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John Gregory Booth

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**SEDIMENT AND PARTICULATE ORGANIC CARBON
TRANSPORT DYNAMICS IN THE BARATARIA BASIN,
LOUISIANA**

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Oceanography and Coastal Sciences

by

John Gregory Booth
B.S., University of Southeast Missouri, 1988
M.S., Louisiana State University, 1994
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DEDICATION

I dedicate this dissertation to my wife, Lori, and our sons, John Garrett Booth and Jacob Scott Booth; and in loving memory of family members who passed away during this time, Gene Booth, Ford Gremillion and Joshua Gremillion.

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ABSTRACT

The transport of sediment and particulate organic carbon (POC) in the Barataria Basin was examined using techniques from the fields of geochemistry, remote sensing and environmental modeling. Monthly (deposition) and decadal (burial) rates of sediment and POC transport were quantified from bottom sediment samples. Sediment and POC deposition rates, based on ^7Be inventories, ranged from $-1.6\text{E}3$ to $1.42\text{E}4 \text{ g m}^{-2} \text{ yr}^{-1}$ and 122 to 1066 $\text{g C m}^{-2} \text{ yr}^{-1}$, respectively. Sediment and POC burial rates, based on excess ^{210}Pb down-core distributions, ranged from $3.8\text{E}2$ to $2.0\text{E}3 \text{ g m}^{-2} \text{ yr}^{-1}$ and 27 to 37 $\text{g C m}^{-2} \text{ yr}^{-1}$, respectively. Deposition rates varied with location in the basin in response to seasonal wind patterns, whereas burial rates were likely the result of stronger weather events such as tropical storms and hurricanes. A comparison of deposition and burial rates indicates that 2 to 7% of the annually deposited POC was buried in bottom sediments of open water environments. Physical transport (not remineralization) accounts for the majority of the difference between POC deposition and burial at the two locations examined, as 3 to 10% of the annually deposited sediment was buried at the same locations.

An empirical model of sediment resuspension as a function of wind speed, direction, fetch and water depth was derived from wave theory and validated using satellite remotely sensed radiance information. Seasonal resuspension characteristics reveal that resuspension is most intense between late fall and early spring. Model predictions of the critical wind speed required to induce resuspension indicate that winds of 4 m/s (averaged over all wind directions) resuspend approximately 50% of

bottom sediments (on an areal basis) in the water bodies examined. Winds of this magnitude (4 m/s) occurred 80 % of the time during the late fall, winter and early spring and approximately 30 % of the time during the summer. More than 50% of the bottom sediments were resuspended throughout the year, indicating the importance of resuspension as a process affecting sediment and biogeochemical fluxes in the Barataria Basin.

OVERVIEW

SEDIMENT AND PARTICULATE ORGANIC CARBON TRANSPORT DYNAMICS IN THE BARATARIA BASIN, LOUISIANA

IMPORTANCE OF COASTAL ENVIRONMENTS

Ocean margins comprise approximately 10 % and 0.5 % of the surface area and volume of the world's oceans; respectively (Mantoura et al., 1991). However, despite their small size, in a recent attempt to value the world's ecosystems, coastal seas were ranked higher than the whole terrestrial or open ocean system (Costanza et al., 1997). These environments support social and economic activities such as human habitation, recreation, mineral extraction, oil and gas exploration, and fin and shell fisheries. It is estimated that half of the world's population now resides within 60 km of the coast, and almost all of the world's fish harvest comes from coastal areas and the adjacent upwelling regions (Jickells, 1998).

In the marine biogeochemical cycles of the elements, coastal margins serve to filter the input of continentally derived material, thereby influencing terrestrial and anthropogenic fluxes to the ocean. It is estimated that these environments retain approximately 90% of riverine particulates and the associated trace elements and pollutants (Martin and Windom, 1991; Milliman, 1991) and account for 20 to 30 % of ocean productivity (Wollast, 1981; Berger, 1989; Wollast, 1991). The global flux of river sediment to coastal margins is on the order of 15×10^9 t/yr and is largely (> 80%) derived from tropical and subtropical rivers (i.e. between the latitudes of 30° N and 30° S) (Milliman and Meade, 1983; Milliman, 1991). The importance of these

sediments for element and pollutant transfer between the continents and oceans is well documented (Meybeck, 1982; Martin and Whitfield, 1987; Martin and Windom, 1991; Valette-Silver et. al., 1993). Therefore, the study of tropical and subtropical coastal systems is critical for understanding global biogeochemical budgets. However, to date much of our paradigm for how estuaries process materials is based on studies of temperate coastal environments (Nixon, 1981; Nixon and Pilson, 1983; Kemp and Boynton, 1984; Peterson and Howarth, 1987; Canuel and Martens, 1996).

River dominated ocean margins (RioMars) have unique characteristics that make them important for advancing the understanding of global biogeochemical cycles. These characteristics include (i) direct input of riverine dissolved and particulate loads, (ii) the highest levels of primary productivity in the oceans, (iii) high sedimentation rates, and (iv) intensive diagenetic processes due to the availability of metal oxides and frequent reworking of bottom sediments. It has been shown that the majority (> 90%) of elements and nutrients transported in global rivers arrive at coastal margins in the particulate phase (Meybeck, 1982; Martin and Whitfield, 1983), and that coastal sedimentary deposits are a focal site for the biogeochemical transformation of many elements (Berner, 1982; Martin and Windom, 1991; McKee et al., 1996; Keil et al., 1997; Aller, 1998). Therefore, processes affecting the subsequent transport and fate of these coastal margin sediments can have a profound effect on global biogeochemical cycles.

RESEARCH APPROACH

This work is focused on gaining a better understanding of material transport in the nearshore coastal environment. My approach to evaluating transport dynamics

was to examine rates of sedimentation in subaqueous bottom sediments at seasonal (deposition) and decadal (burial) time scales in the river dominated coastal margin of Louisiana. In addition, I examined particulate organic carbon (POC) transport and bottom sediment resuspension from wind-induced waves. I have applied techniques from geochemistry, remote sensing and environmental modeling to examine material transport dynamics in the Barataria Basin.

I chose to work in the Barataria Basin as it represents an endmember in the life cycle of river dominated coastal environments as expressed in coastal Louisiana. Reduced freshwater and sediment input, saltwater intrusion, and subsidence combine to create a nearshore environment that is rapidly deteriorating and transitioning back into an open marine environment. The Barataria is typical of much of coastal Louisiana, as levee construction and canal dredging have significantly altered the natural hydrology and material transport characteristics. An extensive amount of work has been completed in the Barataria; however, much of these efforts have focused on aspects of the water column and surrounding marshes to understand the transport and transformation of material, whereas little attention has been given to subaqueous bottom sediments, which are the focus of this work.

There have been many studies of long-term sedimentation (i.e. ^{210}Pb derived rates) in coastal marine sediment deposits. However, this long-term rate, which averages over decades of sedimentation processes, may not be indicative of short-term material transport in these dynamic environments. Furthermore, the processes controlling sedimentation at these different time scales are likely to be important for

understanding the transformations that have been documented to occur in deltaic sediment deposits. In Chapter 1, deposition and burial rates for bulk particulate material are examined using the naturally occurring radioisotopes ^7Be (53 day half-life) and ^{210}Pb (22.3 year half-life).

Shallow, turbid estuaries, like the Barataria, are known to be highly productive due to a well mixed water column with sufficient light and nutrients (Boynton et al., 1982; Kemp and Boynton, 1984; Day et al., 1989). These environments are potentially important reservoirs in the global carbon cycle due to an abundant supply of organic carbon (allochthonous input of terrigenous carbon and autochthonous input of marine carbon) and high rates of sedimentation, which may serve to increase the burial efficiency of organic carbon. In Chapter 2, POC transport characteristics are quantified from the sediments used to determine rates of bulk particle deposition and burial in Chapter 1.

Physical processes (e.g. vertical mixing and sediment resuspension) influence important estuarine parameters such as primary and secondary productivity, sediment mass flux, and pollutant dispersal. Storms have previously been recognized as important forcing mechanisms for sediment transport in continental shelf environments (Drake and Cacchione, 1985 and 1986; Cacchione et al., 1987) and in coastal Louisiana (Roberts et al., 1988; Moeller et al., 1993). In shallow, micro-tidal coastal environments, such as the Barataria Basin, wind induced waves can be the dominant physical forcing mechanism (Ward, 1980; Schroeder and Wiseman, 1999). In Chapter 3, the seasonal characteristics of material transport

were examined using an empirical model of sediment resuspension as a function of wind direction, wind speed, fetch over water and water depth. The model was verified using satellite remotely sensed radiance information (i.e. visible and near-IR channels) from the AVHRR instrument.

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CHAPTER 1

THE TRANSPORT AND FATE OF PARTICULATE MATERIAL IN A SHALLOW, TURBID ESTUARY: SEASONAL AND DECADAL CHARACTERISTICS FROM ^7Be AND ^{210}Pb TECHNIQUES

INTRODUCTION

It is generally accepted that coastal margins are important in global biogeochemical cycles. How coastal margins function as sources and or sinks for organic and inorganic constituents and ultimately mediate the flux of these materials to the ocean remains to be fully resolved (Mantoura et. al., 1991). The major path by which most products of continental weathering (chemical and physical) reach the coast is transport by rivers. The mixing of river water with seawater creates strong gradients in salinity, ionic strength and pH, creating a dynamic aquatic environment where chemical, biological and physical processes collectively can remove trace elements from the water column to the seafloor at rates orders of magnitude greater than in open ocean environments. Sediments play a significant role in the overall transfer and fate of materials in coastal margin environments (Sholkovitz, 1976; Martin and Meybeck, 1979; Martin and Windom, 1991). Coastal sediments are a focal site for the biogeochemical transformation of many elements and therefore their study is critical in understanding oceanic mass balances, as well as residence times for most elements (Holland, 1978; Berner, 1982; Martin and Windom, 1991; Bauer and Druffel, 1998). Studies have shown that estuaries can act as both a source and a sink for elements as they are transported to the ocean (Sholkovitz, 1976;

Moore, 1990). Sediments are important substrates in the transfer of natural and anthropogenic substances from the continents to the oceans. Therefore, knowledge of the dominant mechanisms influencing the transport and fate of sediments in coastal environments will increase our understanding of the processing and transfer of materials from the continents to the oceans.

Here, we investigate sediment transport in the Barataria Basin, LA over time scales ranging from months to decades by measuring naturally occurring radioisotopes in subaqueous bottom sediments. Short term rates were determined from ^7Be inventories and long term rates were determined from the down-core distribution of excess ^{210}Pb .

Certain naturally occurring (e.g. ^7Be , ^{210}Pb) and anthropogenic (e.g. ^{137}Cs , $^{239,240}\text{Pu}$) radionuclides have proven to be useful tracers of particulate material in aquatic environments. Due to quantifiable sources, particle reactive elemental chemistries and radioactive decay it is possible to apply these radionuclides to determine rates of sedimentary processes, such as deposition and burial. The half-life of ^7Be ($t_{1/2} = 53$ days) makes it useful for studying short-term (e.g. monthly) sediment transport characteristics (i.e. deposition). The half-life of ^{210}Pb ($t_{1/2} = 22$ years) enables it to be applied in determining long-term (e.g. decade to century) sediment transport characteristics (i.e. burial). The distribution of ^{137}Cs and $^{239,240}\text{Pu}$ in bottom sediments can also be useful for quantifying sediment transport integrated over several decades.

Beryllium 7 is formed by cosmic ray spallation of nitrogen and oxygen nuclei in the Earth's atmosphere (Arnold and Al-Salih, 1956; Lal et al., 1958). Once produced, ^7Be rapidly associates with aerosol particles and is delivered to the surface of the earth through precipitation and dry deposition (Young and Silker, 1980; Moore et al., 1980; Dibb, 1989). Beryllium 7 is predominantly generated in the stratosphere due to the nucleonic cascade initiated at the top of the atmosphere by cosmic radiation (Lal et al., 1958). However, because the residence time of stratospheric air (>1 yr.) is much greater than the mean life of ^7Be ($1/\lambda = 77$ days) (Bleichrodt, 1978), the majority of ^7Be delivered to the surface of the earth is from the troposphere (Dutkiewicz and Hussain, 1985; Todd et al., 1989; Baskaran et al., 1993; Baskaran, 1995). Following deposition, ^7Be rapidly associates with suspended particulate matter in aquatic systems and thus may serve as an analog for particulate material transport (Olsen et al., 1985, 1986; Dibb, 1989; Canuel et al., 1990; Baskaran and Santschi, 1993).

The decay of the naturally occurring radionuclide ^{238}U produces a suite of daughter products which includes ^{210}Pb . Natural fractionation of these daughter nuclides occurs during weathering and transport in the environment and leads to radioactive disequilibrium between some nuclides and their respective radiogenic parent. The diffusion of ^{222}Rn (a noble gas) from the continent into the atmosphere, its subsequent decay ($t_{1/2} = 3.8$ d) and that of its daughters ($t_{1/2}$ from 1.6×10^{-4} s to 27 min), creates an atmospheric source of ^{210}Pb . When this ^{210}Pb is deposited onto areas such as lakes and other water bodies whose sediments have not lost ^{222}Rn , there

is an excess amount of ^{210}Pb not in equilibrium with the radiogenic parent ^{226}Ra . This ^{210}Pb is often referred to as “excess” and decays with its own 22.3 year half-life. Therefore, the combination of radioactive disequilibrium, chemistry (particle reactive) and half-life (22.3 yr.) enables ^{210}Pb to be useful as a geochronological tool for integrating sedimentation rates over the last 100 – 150 years (Krishnaswami et al., 1971).

STUDY AREA

General Description

The Barataria Basin is an interdistributary estuarine-wetland system located in southeast Louisiana (Figure 1). It is bordered on the north and east by the Mississippi River and on the west by Bayou Lafourche. Coastal Louisiana was formed over the past several thousand years by deltaic sedimentation associated with the discharge of the Mississippi River (Morgan, 1967). The Barataria Basin began forming approximately 3000 years ago, and is comprised of four periods of deltaic advance; 1) the St. Bernard Lobe (1700 – 4000 years ago), 2) the Lafourche Lobe (60 – 3500 years ago), 3) the Plaquemines Lobe (200 – 1000 years ago), and 4) the presently active Balize complex (~ 200 years old) (Baumann and Adams, 1981). The basin has a total area of approximately 6343 km², including 2040 km² of open water and 2080 km² of marsh (Conner and Day, 1987)(Figure 2). Morphological characteristics include levees (natural and artificial), canals, bayous, bays, lakes, swamp and marsh wetlands, and barrier islands (Conner and Day, 1987). Geomorphically, the Barataria estuary is a bar-built lagoon; it is shallow with sand

bars at the mouth and has a small tidal range (Adams et al., 1976). The average depth of open water bodies is approximately 2 meters (Conner and Day, 1987). Tides in the basin are diurnal with an average range of 32 cm at the coast (Baumann, 1987). On average, coastal Louisiana receives about 160 cm of precipitation annually (Baumann, 1987). This precipitation occurs throughout the year, but frequently attains a maximum in July and a minimum in October (Baumann, 1987). Presently, the basin is experiencing reduced freshwater input, increasing salinity and wetland erosion, resulting in a rapid transition back to an open marine environment (Madden et al., 1989).

Hydrology

The Barataria Basin is a meteorologically forced, micro-tidal estuary (Boesch et al., 1989). Water movement through the basin is a function of tidal influence, winds and precipitation. Seasonal water level in the basin exhibits a bimodal distribution with maximum water levels occurring in the spring, due to precipitation and runoff, and summer, due to an expanding Gulf water mass (Baumann, 1987). The spring peak is discernable but considerably attenuated, by decreased upland runoff, for locations in the lower basin (Baumann, 1987).

The natural hydrology of the basin has been altered extensively by human activities (i.e. channel dredging and levee construction) (Turner and Cahoon, 1988). Indeed, leveeing of the Mississippi River has effectively eliminated the major fluvial input of freshwater and sediments to the basin, making precipitation the primary source of freshwater. Linear canals dredged to depths greater than the surrounding

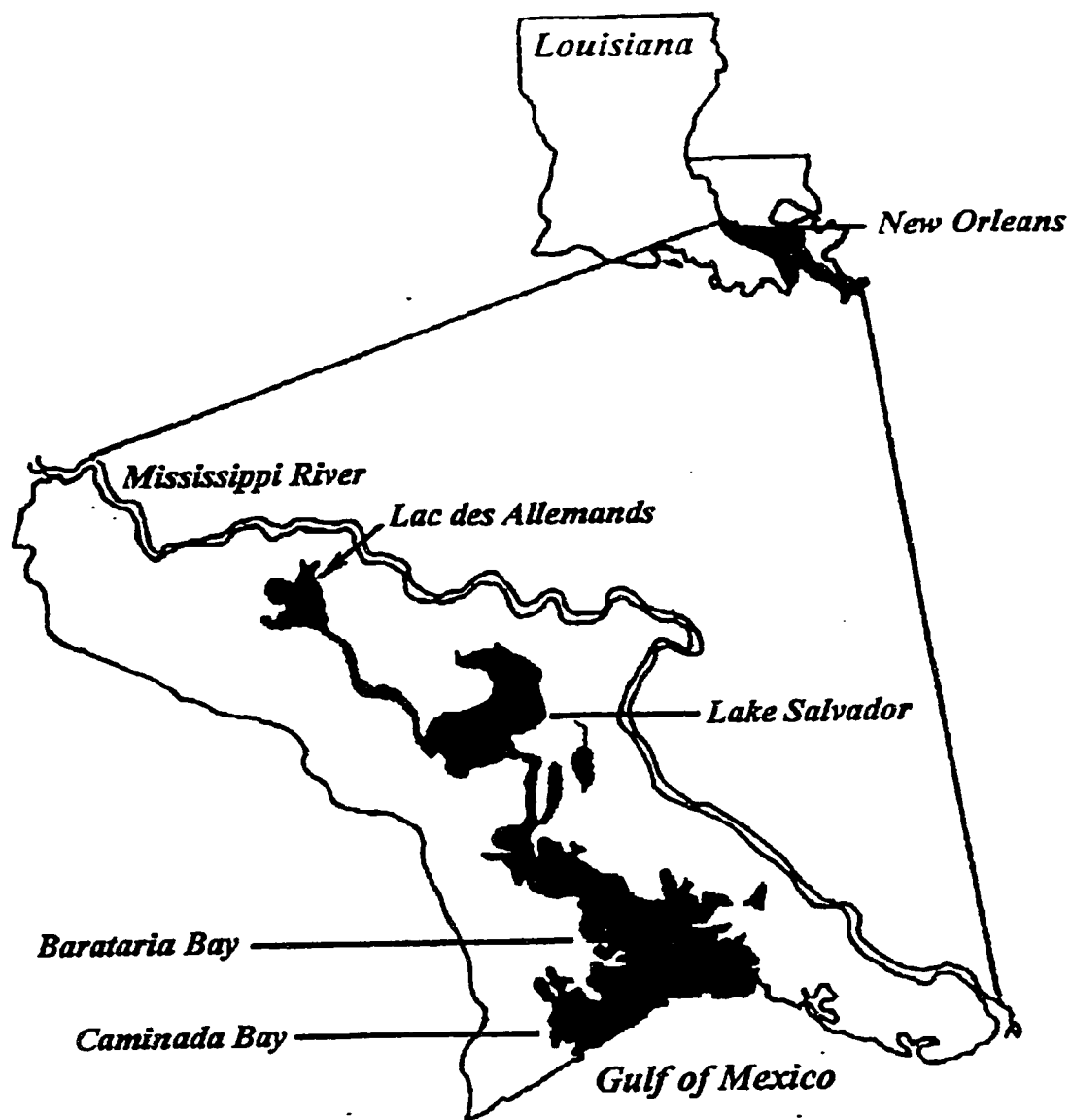


Figure 1.1. Location of the Barataria Basin with major water bodies identified.

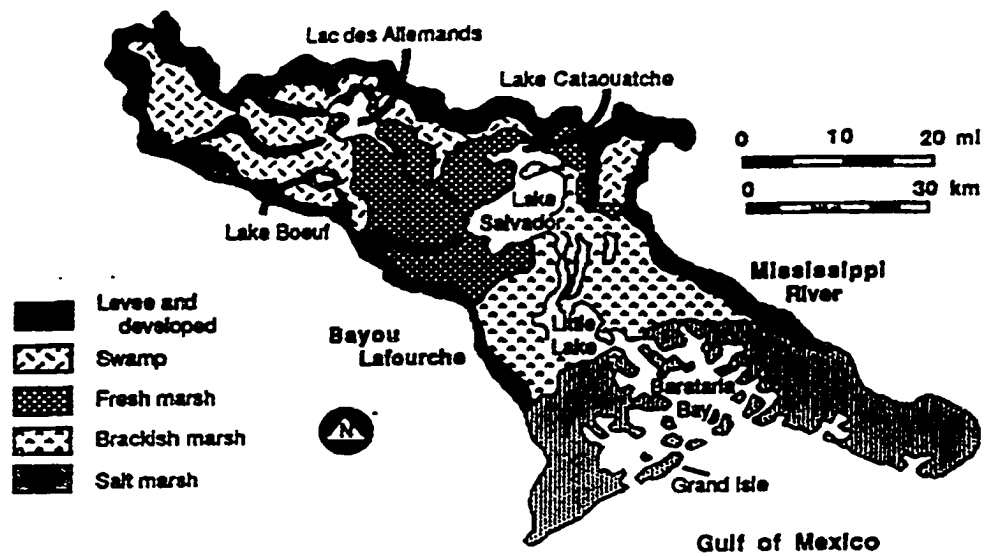


Figure 1.2. Habitat map of the Barataria Basin (from Conner and Day, 1987).

bay bottoms allow the intrusion of high salinity water into the interior basin, and also provide efficient conduits for the transport of sediments and nutrients out of the basin. Likely, the overall effect of these activities has been to decrease the transfer of sediments to the marsh surface, thereby decreasing the sustainable marsh area of the basin.

Material Transport

The transfer of material (e.g. silt, clay, organic matter and nutrients) within the basin is dependent on water movement. Historically the bulk of material transport occurred in the spring in concert with the annual river flood. Presently, maximum water exchange in the Barataria occurs in the fall and winter in response to the passage of cold fronts (Baumann, 1987; Madden et al., 1988). During this time an average of 5.7 frontal passages occur on a monthly basis (Baumann, 1987). As a cold front approaches the coast from the north, southerly component winds strengthen and push water into the basin, flooding the marshes. After the front passes, northerly component winds become dominant and push the water out of the basin, draining the marshes. Water level variability in the marsh approaching 1 m d^{-1} has been documented in relation to wind stress (Muller, 1979). This scenario is repeated for each frontal passage and has been shown to be important for material transport in the basin. Storm passages are now the only mechanism that transports sediments to the surface of the marsh. A study of the seasonality of marsh accretion indicates that winter storm passages can account for as much as 75% of the annual accretion, in years when tropical storms do not impact the basin (Baumann et al.,

1984). The source of these sediments is primarily bottom sediments from lakes and bays (Madden et al., 1988).

Sampling Sites

Samples were collected in brackish (Little Lake) and saline (Live Oak Bay) environments (Figure 3). Little Lake is shallow (~ 1.5 m) and moderately productive for coastal Louisiana ($1307 \text{ g O}_2 \text{ m}^{-2} \text{ yr}^{-1}$) with a salinity range of 0 – 15 psu (Madden et al., 1989 and references therein). Bayou Perot, which empties into the northern end of Little Lake, provides a direct connection to Lake Salvador, the largest water body in the middle basin. Generally, from Lake Salvador south the waters of the basin receive less anthropogenic nutrients and are representative of a natural environment responding to decreased river influence, with respect to nutrient dynamics and primary productivity (Madden et al., 1989). Live Oak Bay is a small embayment located on the western side of Barataria Bay; which is one of the primary water bodies making up the basin's estuary. Live Oak Bay is shallow (~2 m) with a silty-clay substrate. A bayou draining the surrounding marsh (*spartina alterniflora*) empties into the northern end of Live Oak Bay. Material transport in the bayou has been shown to be dominated by cold front and tropical storm passages (Rovansek, 1997).

METHODS

Atmospheric Samples

Atmospheric bulk deposition samples (wet and dry combined) were collected from hydrologic platforms (~ 3 meters above the water surface) installed at or near

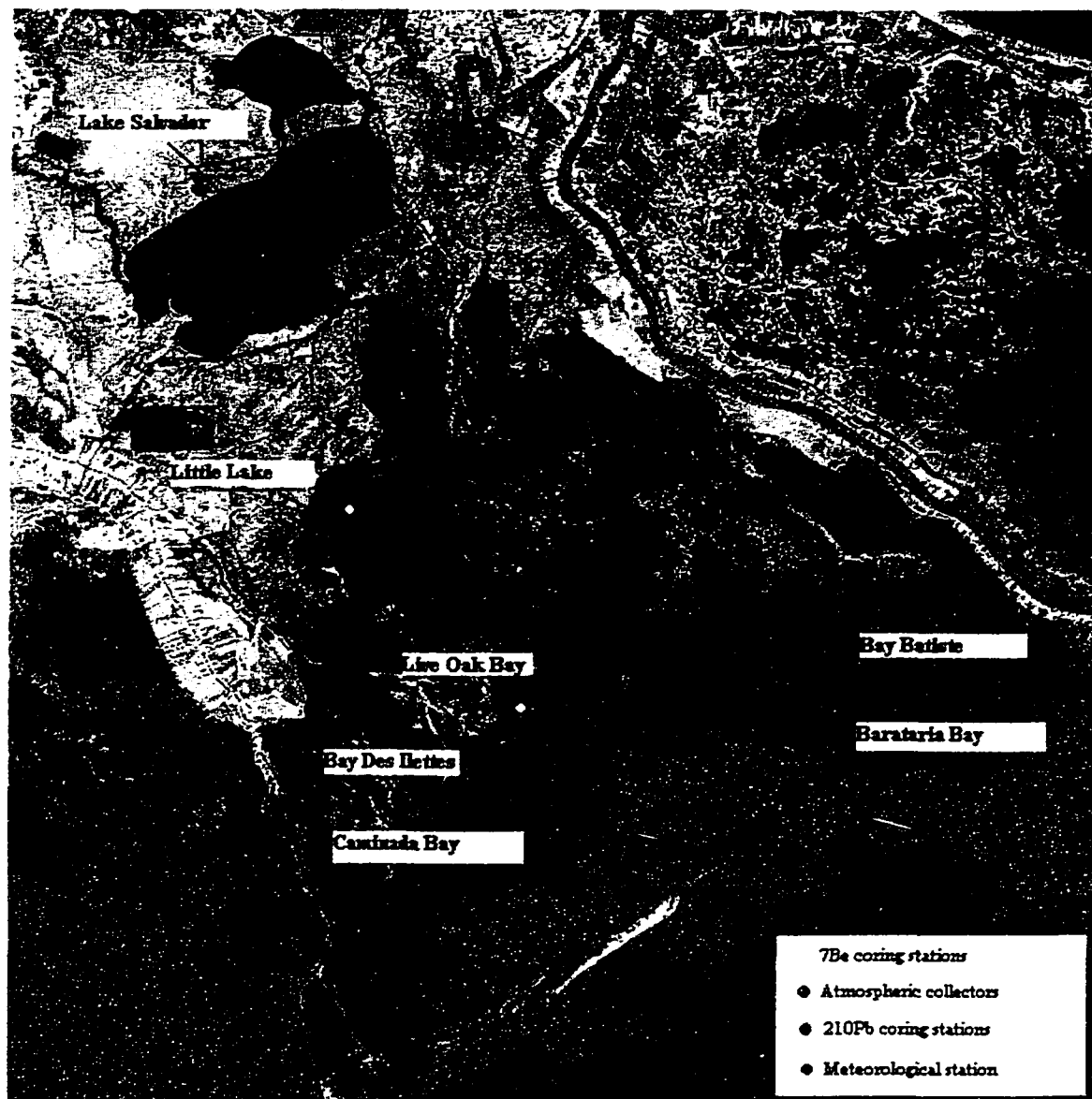


Figure 1.3. Locations of sample sites, atmospheric collectors and meteorological buoy.

(< 5 km away) the designated sampling stations. The samples were collected using a polyethylene container (10 liters) and funnel (20.3-cm diameter) with an effective surface area of 324.3 cm². The amount of precipitation occurring within each sampling period was not measured during this study.

Prior to deployment the containers were acidified with 50ml of 14N HNO₃ to inhibit wall adsorption, and on three occasions a beryllium standard (1ml at 1mg Be per ml in 1% HNO₃ Sigma Chemical Co.) was added in order to quantify recovery. At the conclusion of each sampling period, the containers were collected and replaced with new containers treated as described above. The containers were then sealed and transported back to the laboratory where they were allowed to evaporate inside a fume hood to a volume of less than one liter. The samples were then transferred into one liter Teflon beakers (each container was acid washed and the rinses added back to the sample). The beaker was gently heated and the sample evaporated to a volume of approximately 12 ml. The sample was then transferred into a petri dish (50 mm x 9 mm) (again the container was acid washed and the rinses added back to the sample) with the final volume being adjusted to approximately 18 milliliters (ml).

Sediment Samples for Deposition and Burial

Sediment cores were gathered from a small boat with a hand-held PVC coring device. The core tube was gently pushed into the bottom sediments to obtain a vertical column of sediment. Cores for short-term deposition were collected at 4 to 6 week intervals at Little Lake and Live Oak Bay (Fig. 3). These sediments were

immediately extruded and subsectioned to a depth of 5 cm. The top 1cm was sampled at 0.5 cm intervals and thereafter 1 cm intervals were collected. The wet sediments from each sampling interval were transferred into a petri dish (50 mm x 9 mm) for ^7Be activity measurement.

In order to quantify long-term sediment burial rates, nine cores were collected throughout the basin in the same manner as above (Figure 3). The cores were extruded at 1-cm intervals to a depth of approximately 30 cm.

Laboratory Analyses

Atmospheric and short-term deposition samples were analyzed by gamma ray spectrometry (PGT intrinsic germanium, planar type detector) and multi-channel analyzer. Atmospheric samples were counted for approximately 24 hours; while sediment samples were counted for 48 – 120 hours. Counting efficiencies were determined by placing a mixed gamma source (IAEA-300, Black Sea sediments) into a petri dish (50 mm x 9 mm) and quantifying gamma emitters over a range of energies (46.5 – 1460 KeV). Linear interpolation between the ^{214}Pb peak at 351.9 KeV and the ^{214}Bi peak at 609.3 KeV was used to quantify the counting efficiency for ^7Be centered at 477.6 KeV. Recoveries for the Beryllium standard were determined by atomic absorption analyses and ranged from 85 – 100%. All errors are statistical counting errors expressed as ± 1 standard deviation, excluding ^7Be inventory errors. The activity of ^7Be in each sampling period was decay corrected to the mid-point of the sampling period using the $C = C_0 e^{-\lambda t}$ relationship where “t”

equals one-half the number of days in each sampling period. Bottom sediment beryllium activities are reported on a dpm g^{-1} dry weight basis.

Sediment burial rates were determined by quantifying ^{210}Pb via its Polonium (^{210}Po) daughter. A commercial microwave digestion system (CEM-MDS-81D) was used for this study. Briefly, each section was dried ($\sim 60^\circ \text{C}$) and ground into a fine powder using a mortar and pestle. A 1 - 3 g aliquot of sediment was placed into a Teflon vessel and spiked with 1 ml of the yield tracer ^{209}Po in 5N HNO_3 (activity = 10.01 dpm/ml). The sediment was leached in concentrated HCL (10ml) for 10 minutes at 50 psi and again for 30 minutes at 100 psi. The sediments were transferred into centrifuge tubes with deionized water and centrifuged for 5 minutes. The supernatant was then transferred into a glass beaker, the pH adjusted to 8 - 9 with ammonium hydroxide causing the Fe oxyhydroxides to precipitate. The samples were transferred into centrifuge tubes and centrifuged again for 3 minutes. The supernatant was removed and 1.25 ml of concentrated HCL added to dissolve the precipitate. Ascorbic acid was added to reduce the iron present in the solution and the pH adjusted to between 2 - 3. A 0.75 cm diameter silver planchet was placed in the centrifuge tube and the polonium allowed to auto-electroplate for 48 - 72 hours. Each planchet was then analyzed for ^{209}Po and ^{210}Po via alpha spectroscopy using Canberra Quad and Ortec Octet detector configurations (Si-surface barrier detectors). Samples were counted for approximately 48 hours or until an appropriate amount of counts were acquired to insure sufficient accuracy and precision.

Seasonal Sediment Transport (Deposition)

Inventories were calculated according to the following equation

$$I (\text{dpm/cm}^2) = X_i (1 - \phi) (\rho_s) (A_i), \quad (1)$$

where X_i is the sample interval thickness (cm), ρ_s is the dry particle density (g cm^{-3}), A_i is the activity of ^7Be (dpm g^{-1}) and ϕ is the bottom sediment porosity where $\phi = (w_2 - w_3/\rho_w) / [(w_2 - w_3/\rho_w) + (w_3 - w_1/\rho_s)]$, where w_1 is the container weight (g), w_2 is the wet sediment weight (g), w_3 is the dry sediment weight (g), ρ_w is the density of water (1.01 g cm^{-3}) and ρ_s is the density of sediments (2.5 g cm^{-3}).

Total bottom sediment ^7Be inventories were separated into two components, residual inventory and new inventory, after the technique presented by Canuel et al., 1989. The residual inventory accounts for the ^7Be inventory from the previous sampling period, decay corrected to the subsequent sampling period. The difference between the total inventory and the residual inventory represents the new inventory, which accounts for material deposited to the site during the time between sample collection. Therefore, if the total inventory is equal to the residual inventory (or the total inventory was entirely residual) then this would indicate no net sediment delivery or loss during the sampling period. However, if the residual inventory were greater than the total inventory this would indicate net sediment removal during the sampling period. If the residual inventory were less than the total inventory this would indicate net sediment deposition during the sampling period. Short-term sediment deposition rates were calculated by dividing the new inventory (dpm/cm^2) by the mean new activity (dpm/g) yielding mass deposition (g/cm^2). The mean new

activity is the mean activity of the new inventory. This method of calculation was used so that monthly rates of deposition could be quantified.

Horizontal Variability in Surface Sediments

In order to assess the horizontal variability in beryllium inventories at each station ten cores were collected within a 12-m diameter circle at each beryllium site. The top 3 centimeters from each core were homogenized and analyzed for ^7Be , ^{137}Cs , ^{210}Pb and ^{40}K . The coefficient of variability (CV) for ^7Be from these samples was included in the estimate of error for short-term deposition rates.

Long-term Sediment Transport (Burial)

Lead-210 has been successfully used to determine rates of sedimentation in coastal environments (Bruland et al., 1974; Nittrouer et al., 1979; Lynch et al., 1989; Mckee et al., 1995; Kuehl et al., 1995; Kuehl et al., 1996; Allison et al., 1996). Additionally, human impact and pollution studies rely on ^{210}Pb and marker horizon techniques to reconstruct modern anthropogenic fluxes (Valette-Silver et al., 1993; Ravichandran et al., 1995b). When applying the ^{210}Pb dating technique the common assumptions are: 1) activity of excess ^{210}Pb arriving to bottom sediments remains constant with time; 2) negligible remobilization of ^{210}Pb or ^{222}Rn occurs in the sediments; 3) the residence time for ^{210}Pb in the water column is short in comparison to the flushing time of the water body; and 4) that excess ^{210}Pb can be calculated from the total ^{210}Pb and ^{226}Ra activity in the sediments. Frequently, the assumption that the ^{226}Ra activity is constant throughout a core is made, and thus its activity can

be determined from the constant ^{210}Pb activity at depth, where the two nuclides are in radioactive equilibrium.

Generally, it appears that the ^{210}Pb dating technique provides accurate sedimentation rates (Nitttrouer et al., 1979; Lynch et al., 1989; Kuehl et al., 1995 and 1996; Allison et al., 1996). However, there are documented instances of disagreement between ^{210}Pb and other dating methods (primarily bomb fallout tracers) (Baskaran et al., 1997; Wan et al., 1987; Ravichandran et al., 1995a; Bloesch and Evans, 1982).

In near shore environments, surface sediments are typically continually mixed on the time scale of ^{210}Pb decay and exhibit a vertically linear activity profile for excess ^{210}Pb . If we assume that the ^{210}Pb activity of sediments depositing out of the mixed layer is constant, then from an exponential decrease in ^{210}Pb activity with depth we can obtain a sedimentation rate using,

$$(A_{xs})_t = (A_{xs})_{t=0} e^{(-\lambda t)}, \quad (2)$$

$$(A_{xs})_t / (A_{xs})_{t=0} = e^{(-\lambda t)}, \quad (3)$$

$$\ln[(A_{xs})_t - (A_{xs})_{t=0}] = -\lambda t \quad (4)$$

where $(A_{xs})_t$ is the excess activity at depth for some time (t), $(A_{xs})_{t=0}$ is the excess activity at the initial time, at the sediment surface or in sediments directly beneath the mixed layer, λ is the decay constant for ^{210}Pb (0.03114 yr^{-1}), and t is time in years. If we assume that the sedimentation rate is constant then,

$$t = z/s \quad (5)$$

where z represents depth (cm) in the sediment core and s is the sedimentation rate (cm yr⁻¹). By substituting equation 5 and rearranging equation 4 to obtain $-\lambda/s$ we find

$$\ln(A_{xs}) = -\lambda z/s, \quad (6)$$

$$\ln(A_{xs}) = (-\lambda/s) z. \quad (7)$$

Linear regression analysis is used to solve for $(-\lambda/s)$ in the log transformed equation for radioactive decay. When plotted as $\ln(A_{xs})$ vs z the slope of the regression line is equal to $(-\lambda/s)$.

RESULTS

Precipitation

For the time period of this study the average annual precipitation between New Orleans and Grand Isle weather stations was 167.5 cm, with the maximum and minimum rainfall occurring during the summer and fall, respectively (Figure 4). Because the Grand Isle weather station is closer to each sampling station than the New Orleans weather station and is located in the Barataria Basin, only the data from this location are used to characterize precipitation delivery with ⁷Be data collected during this study.

Atmospheric Flux of ⁷Be

Total (wet and dry) atmospheric deposition of ⁷Be was collected over the 15-month period from September 1995 to January 1997. Daily flux data ranged from 0.02 to 0.16 dpm cm⁻² with a mean ($n = 20$) of 0.07 dpm cm⁻² (Figure 5). This mean daily flux is within the range of values reported in the literature, 0.02 – 0.1 dpm cm⁻²

Table 1.1. Atmospheric deposition (inventories) of ^7Be at Little Lake (LLN) and Live Oak Bay (LOB).

	LOB	LLN	
Sample ID	Inventory (dpm cm ⁻²)	Inventory (dpm cm ⁻²)	Days Collecting
11/15/95	3.24 (± 0.04) [†]	1.87 (± 0.06)	50
01/04/96	1.18 (± 0.03)	2.09 (± 0.06)	50
02/25/96	2.28 (± 0.08)	3.4 (± 0.16)	52
04/03/96	2.03 (± 0.04)	0.85 (0.05)	39
05/21/96	2.42 (± 0.05)	2.15 (± 0.08)	48
07/01/96	3.50 (± 0.13)	3.81 (± 0.13)	40
08/19/96	5.77 (± 0.17)	4.42 (± 0.15)	49
09/23/96	5.52 (± 0.07)	5.58 (± 0.05)	34
10/29/96	1.65 (± 0.07)	2.6 (± 0.06)	30
01/03/97	3.46 (± 0.12)	5.08 (± 0.06)	65
Mean	3.11	3.19	45.7
[†] Errors represent statistical counting errors			

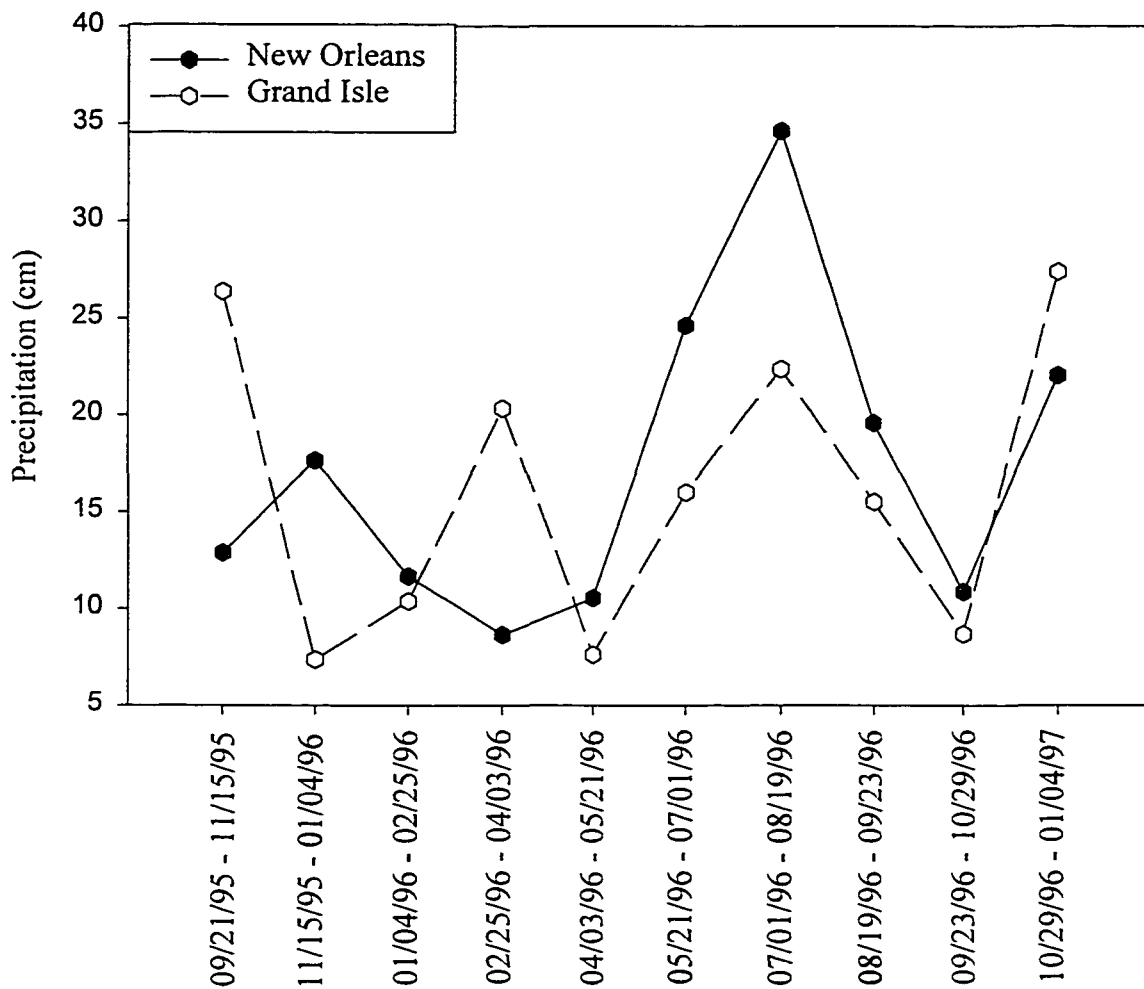


Figure 1.4. Precipitation characteristics for Grand Isle and New Orleans during the fifteen-month study period.

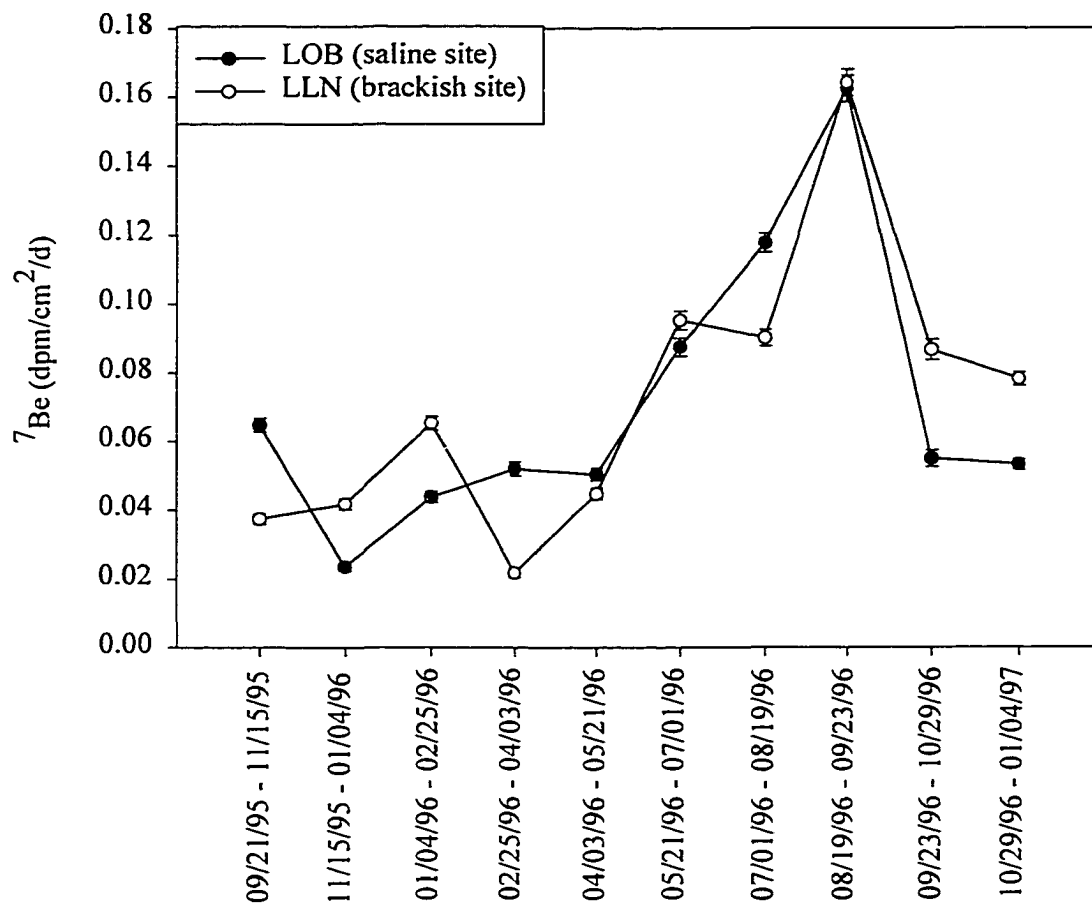


Figure 1.5. Atmospheric deposition of beryllium at Little Lake (LLN) and Live Oak Bay (LOB) in the Barataria Basin.

(Baskaran et. al., 1993; Canuel et. al., 1990 and references within). Based on the mean life of ^7Be ($1/\lambda = 77$ days) this flux would support a steady state inventory of 5.4 dpm cm^{-2} . The annual flux of ^7Be to the basin was measured to be 26 dpm cm^{-2} at the Live Oak Bay (LOB) station, and 24 dpm cm^{-2} at the Little Lake station (LLN), respectively. These values are comparable to previous work on atmospheric ^7Be deposition in the northern Gulf of Mexico region; where the annual flux ranged from $8 - 23 \text{ dpm cm}^{-2}$, with a three year mean flux of $\sim 15 \text{ dpm cm}^{-2}$ (Baskaran et al., 1993; Baskaran, 1995).

Bottom Sediment ^7Be Inventories

Total (residual + new) bottom sediment inventories measured during this study ranged from non-detectable to approximately 19 dpm cm^{-2} (Table 2). The highest inventory values occurred during the late winter and early spring at the LOB station and in the summer at the LLN station. The LOB site had a mean ^7Be inventory (0 - 3 cm) of 8.0 dpm cm^{-2} ($n = 11$); while the LLN site had a mean ^7Be inventory (0 - 3 cm) of 6.3 dpm cm^{-2} ($n = 10$). These values are in excess of the atmospherically supported flux (5.4 dpm cm^{-2}). Mean surface sediment ^7Be activities were seasonally variable at each station, with the highest activities occurring in the spring ($\sim 29 \text{ dpm/g}$) for the LOB station and during the summer ($\sim 44 \text{ dpm/g}$) for the LLN station (Table 2). These activities are several times higher than those reported in the literature for estuarine bottom sediments (Olsen et al., 1986; Dibb and Rice, 1989; Canuel et al., 1990). Seasonal mass deposition rates ranged from -1.61 to 0.50 g cm^{-2} (Table 2).

Table 1.2. Bottom sediment beryllium inventories, beryllium surface activities and bulk particulate mass deposition at Little Lake and Live Oak Bay.

LOB Be-7 Data				
Sample ID	Total Inv. (dpm/cm ²)	New Inv. (dpm/cm ²)	Mean Act. (dpm/g)	Mass Dep. (g/cm ²) ⁴
09/26/95	4.97 (± 2.14) ¹			
11/15/95	8.76 (± 3.77)	6.17 (± 3.93)	12.59 (± 0.64)	0.49 (± 0.31)
01/04/96	7.12 (± 3.06)	2.545 (± 3.64) ³	9.98 (± 0.69)	
02/25/96	10.26 (± 4.41)	6.64 (± 4.68)	17.76 (± 1.43)	0.37 (± 0.26)
04/03/96	11.80 (± 5.07)	5.54 (± 5.74) ³	28.8 (± 1.80)	
05/21/96	5.83 (± 2.51)	(-)1.29 (± 3.95) ³	0.00	
07/01/96	8.33 (± 3.58)	5.17 (± 3.83)	28.77 (± 2.75)	0.18 (± 0.13)
08/19/96	6.47 (± 2.78)	1.51 (± 3.50) ³	19.97 (± 2.27)	
09/23/96	9.56 (± 4.11)	5.66 (± 4.43)	14.86 (± 2.24)	0.38 (± 0.29)
10/29/96	8.94 (± 3.84)	2.88 (± 4.64) ³	16.93 (± 2.24)	
01/03/97	6.38 (± 2.74)	2.54 (± 3.20) ³	23.36 (± 1.51)	
			Total Deposition =	1.42 (± 0.68)³
LLN Be-7 Data				
Sample ID	Total Inv. (dpm/cm ²)	New Inv. (dpm/cm ²)	Mean Act. (dpm/g)	Mass Dep. (g/cm ²) ⁴
11/15/95	6.54 (± 2.68) ²		6.43 (± 0.39)	
01/04/96	6.16 (± 2.53)	2.75 (± 2.89) ³	8.32 (± 0.37)	
02/25/96	4.80 (± 1.97)	1.67 (± 2.35) ³	3.28 (± 0.39)	
04/03/96	0.00	(-) 2.93	0.00	
05/21/96	2.33 (± 0.96)	2.33 (± 0.96)	4.64 (± 0.81)	0.50 (± 0.21)
07/01/96	1.82 (± 0.75)	0.44 (± 0.94) ³	8.64 (± 0.51)	
08/19/96	12.03 (± 4.93)	11.07 (± 4.95)	35.3 (± 3.51)	0.31 (± 0.14)
09/23/96	19.52 (± 8.00)	11.88 (± 8.59)	43.7 (± 4.05)	0.27 (± 0.20)
10/29/96	3.26 (± 1.34)	(-) 8.80 (± 5.13)	5.48 (± 0.94)	(-)1.61 (± 0.94)
01/03/97	6.98 (± 2.86)	5.58 (± 2.92)	14.96 (± 1.72)	0.37 (± 0.19)
			Total Deposition =	(-)0.16 (± 1.01)⁶
¹ Errors based on Coefficient of Variability (0.43) from spatial data				
² Errors based on Coefficient of Variability (0.41) from spatial data				
³ Associated error larger than measurement so assumed no net deposition or removal				
⁴ Net particle deposition since preceeding sample date				
⁵ Total particle deposition from 9/95 to 9/96				
⁶ Total particle deposition from 1/96 to 1/97				

Spatial Variability

The horizontal variability at each station, for ^7Be , ^{210}Pb , ^{137}Cs and ^{40}K is demonstrated by the inventories (Table 3) of ten cores collected about each site. The coefficient of variability (CV) for ^7Be at the LOB site was 43%; while the CV for ^7Be at the LLN site was 41% (Table 3). Spatial variability at the LOB site was greater than the temporal variability ($\sim 25\%$) measured during this study. The LLN station had much higher temporal variability ($> 100\%$) and effectively the same spatial variability ($\sim 41\%$) as compared with the LOB site. Total inventories at the LOB station are reported as $\pm 43\%$; while total inventories at the LLN site are reported as $\pm 41\%$.

Burial Data

Long term sedimentation data from 9 cores are listed in Table 4. Burial rates ranged from 0.08 to 0.25 cm/yr. In general, cores collected from sites which were proximal to wetland vegetation and more sheltered had the highest sedimentation rates (e.g. Live Oak Bay, Bay Batiste and Caminada Bay). The average burial rate for the more protected sites is 0.21 ± 0.04 cm/yr ($n = 3$), while the average burial rate for the less protected sites is 0.11 ± 0.02 cm/yr ($n = 6$).

DISCUSSION

Atmospheric Deposition of ^7Be

Previous studies have shown that the atmospheric flux of beryllium to the Earth's surface is variable (Olsen et al., 1985; Todd et al., 1989; Canuel et al., 1990). The annual ^7Be flux at location is largely controlled by the amount of precipitation

Table 1.3. Spatial Variability for ^7Be , ^{210}Pb , ^{137}Cs and ^{40}K in surface bottom sediments from Little Lake and Live Oak Bay.

Little Lake				
	^7Be Inv. (dpm/cm ²)	^{210}Pb Inv. (dpm/cm ²)	^{137}Cs Inv. (dpm/cm ²)	^{40}K Inv. (dpm/cm ²)
	0.53	8.91	0.67	50.55
	2.30	5.96	0.39	44.79
	1.82	9.90	0.69	55.88
	1.18	7.99	0.54	46.14
	0.35	7.79	0.40	36.08
	1.01	5.63	0.45	58.80
	1.08	7.41	0.45	49.52
	0.82	6.26	0.37	50.04
Mean	1.14	7.48	0.49	48.98
Std. Dev.	0.47	1.17	0.10	4.98
C.V. (%)	41.51	15.60	20.64	10.17
Live Oak Bay				
	^7Be Inv. (dpm/cm ²)	^{210}Pb Inv. (dpm/cm ²)	^{137}Cs Inv. (dpm/cm ²)	^{40}K Inv. (dpm/cm ²)
	2.64	5.64	0.15	45.47
	2.26	7.48	0.42	60.69
	1.48	6.38	0.26	57.45
	1.44	7.31	0.42	49.09
	3.00	5.75	0.21	43.51
	0.57	7.70	0.39	54.48
	1.27	3.19	0.12	42.26
	0.69	5.71	0.29	29.84
Mean	1.67	6.01	0.28	48.19
Std. Dev.	0.72	1.12	0.09	8.27
C.V. (%)	43.44	18.70	30.55	17.17

received (Baskaran, 1993). The seasonal rate of delivery is primarily influenced by differential mixing (i.e. injection) of stratospheric air into the troposphere, and the characteristics (e.g. amount of rainfall and number of rainy days) of the precipitation event(s) (Dibb, 1989; Baskaran, 1995). Dibb, 1989 showed that the specific activity of ^7Be during a single rain event decreased over time. Therefore the characteristics of precipitation at a given location may be as important as the total amount of precipitation, when studying atmospherically derived tracers.

As mentioned previously, precipitation was not quantified at each atmospheric collector site during this study. However, precipitation data were obtained from the Grand Isle weather station, which is located approximately 18 km from the LOB station and approximately 37 km from the LLN station. Precipitation data from the New Orleans airport were also obtained as this represents rainfall at the northeastern boundary of the Barataria Basin. Precipitation data for the Grand Isle and New Orleans stations exhibit similar trends, however the absolute amount of rainfall at each station during this study period differed (Figure 4). Beryllium atmospheric flux data did not exhibit a correlation with rainfall amount (Figure 6). However, the frequency of rain events (i.e. number of rainy days) during each of the ^7Be sampling periods did appear to influence atmospheric fluxes for ^7Be (figure 7). Based on these relationships it is expected that the seasonal atmospheric delivery of

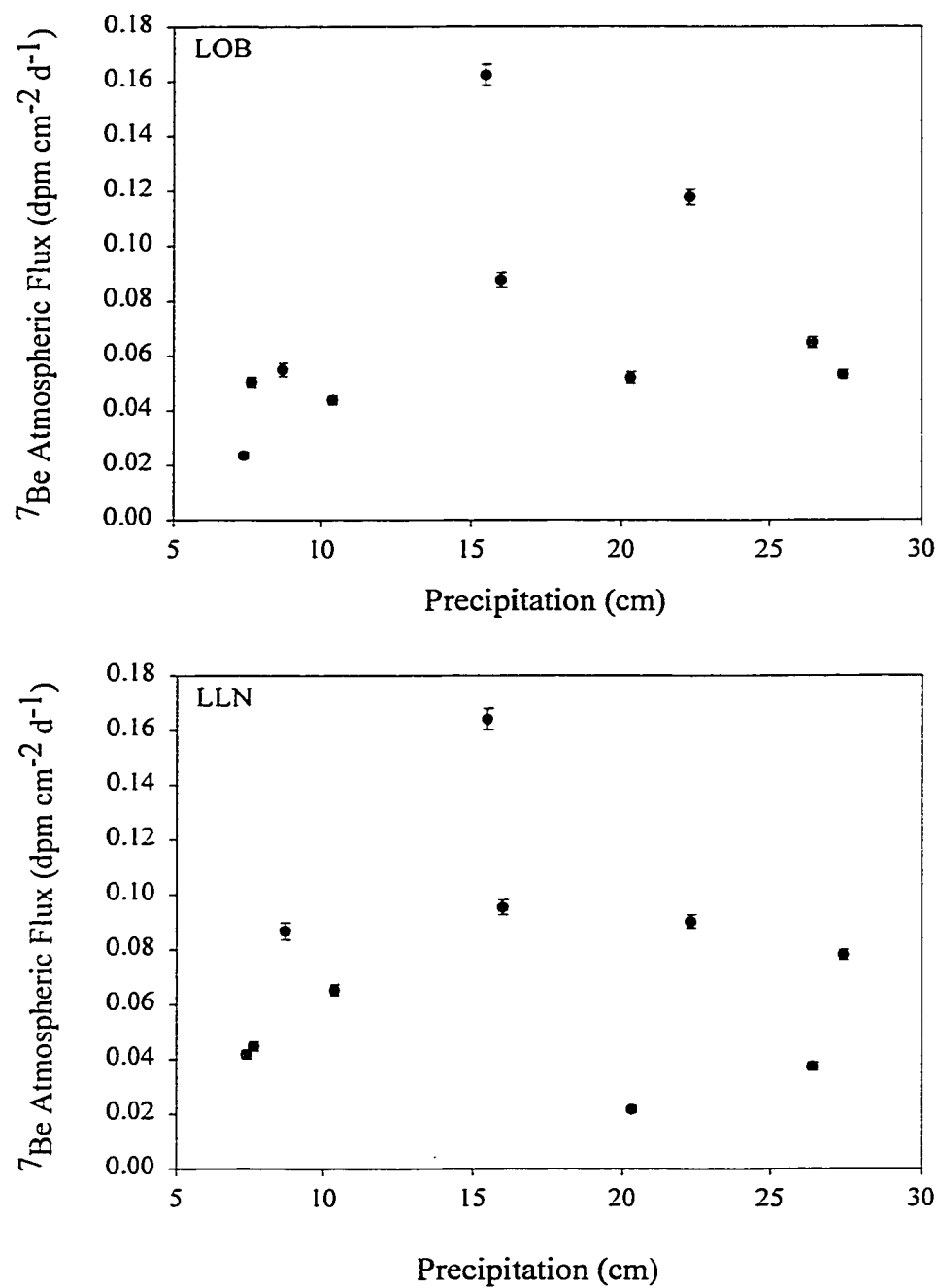


Figure 1.6. ^7Be atmospheric flux vs. precipitation at Little Lake and Live Oak Bay.

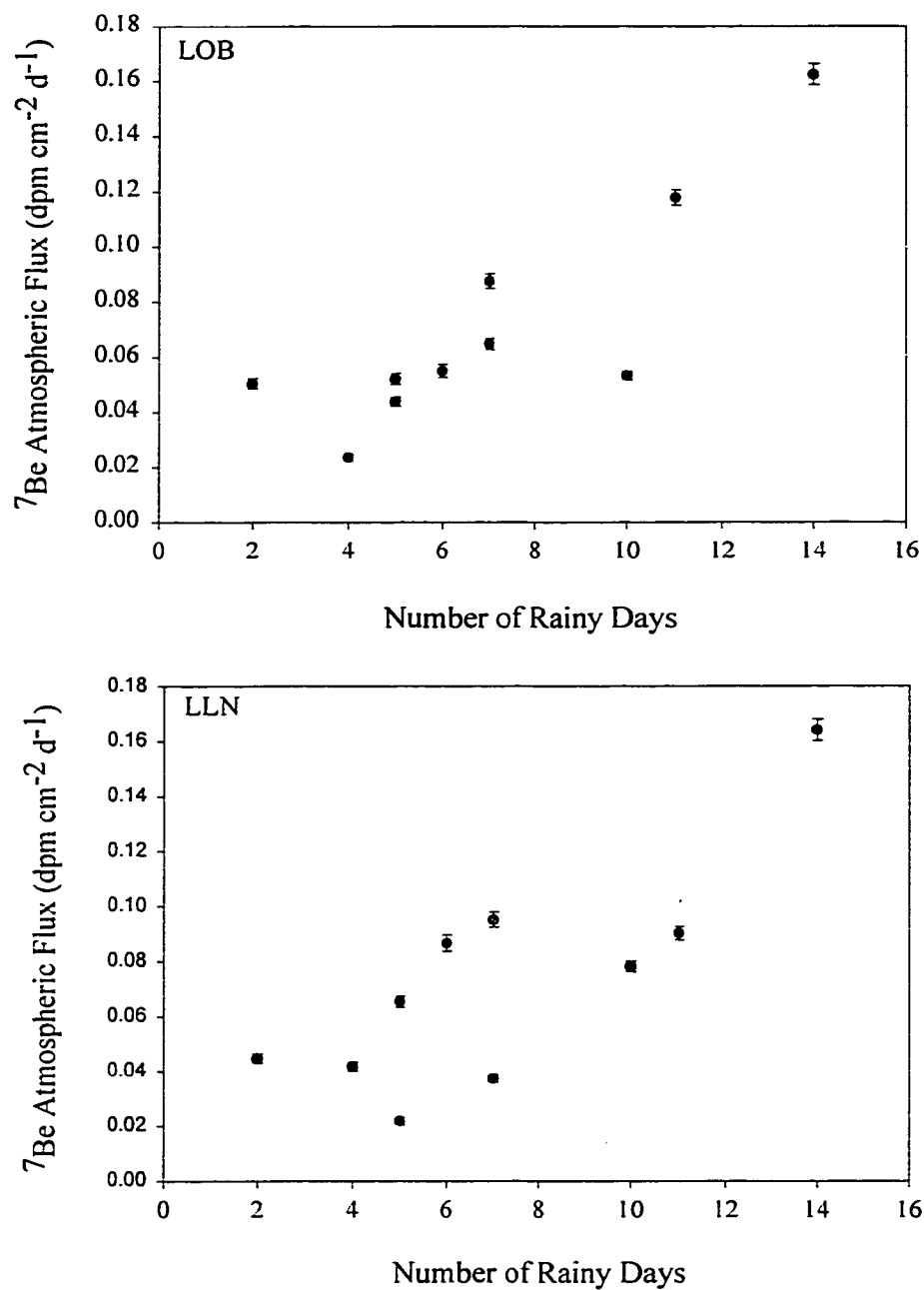


Figure 1.7. ^7Be atmospheric flux vs. precipitation frequency at Little Lake and Live Oak Bay.

^7Be to the various estuaries and aquatic environments in southern Louisiana will be maximal during summer months and minimal during fall and winter months.

During this study seasonal depositional characteristics for ^7Be were very similar between stations, with minimum deposition occurring in late winter or early spring and maximum deposition occurring in the late summer (Figure 5). Spring and summer months accounted for approximately 75% of the ^7Be deposition at the LOB site and 70% at the LLN station. The increasing atmospheric flux of beryllium from spring through summer is likely due to climatic changes resulting in different precipitation characteristics as compared to the fall and winter seasons. During the fall and winter seasons, rainfall occurs in response to frontal passages. This scenario results in more rain per event and fewer events. Therefore, it is expected that ^7Be deposition rates will be lower during these kinds of weather conditions due to atmospheric washout. In contrast, during the spring and more frequently in the summer, rainfall occurs in response to convective heating of the local atmosphere. This scenario results in a higher frequency of events and less rainfall per event. These climatic conditions would result in larger ^7Be deposition rates, particularly if the convective storms entrain stratospheric air.

Bottom Sediment Inventories

Total inventories at the two sampling stations in this study show different seasonal characteristics (Table 2). The LLN station exhibits minimum beryllium inventories during the spring season and maximum inventories during the summer. This is likely due to the physical characteristics of the station (i.e. shallow and

unprotected from wind exposure). During the spring season the passage of cold fronts results in dominant northerly winds which would tend to resuspend and transport sediments away from the station, resulting in lower beryllium inventories. The summer maximum corresponds to the atmospheric deposition maximum, and is likely due to ephemeral, locally variable winds which would effectively resuspend bottom sediments, but would result in limited horizontal transport distances (i.e. only displace sediments locally, as opposed to basin wide transport which occurs with the passage of strong fronts during the spring season). Additionally, summer months typically have prevailing southerly component winds, resulting in up-basin transport. The LOB station exhibits elevated inventories throughout the year as compared to the LLN site, with maximums in the late fall and early spring. Again, these inventories are explainable due to the physical characteristics of the station (i.e. shallow and protected from wind exposure). The LOB station is located proximal to the littoral edge of the estuary and is also influenced by a small bayou located on the northern end of the bay. Maximum bottom sediment inventories of ^7Be in the late fall and early spring correspond with the occurrence of northerly component winds, associated with frontal passages that flush water and sediments out of the surrounding marshes. It is expected that sediments flushed out of the marsh will have a higher specific activity of ^7Be , in comparison to bottom sediments, due to direct exposure to precipitation. This is supported by the persistence of higher inventories and specific activities of surface sediments throughout the year at the LOB station (except during the summer months) (Table 2).

Spatial Variability

At each station the spatial variability inventories are much lower than the average inventories collected temporally (e.g. spatial inventories were approximately 8 times lower than average inventories at the LOB site and approximately 6 times lower at the LLN site) (Tables 2 and 3). Therefore, these are considered to be an overestimate of the errors associated with measuring ^7Be inventories. Unfortunately, the spatial variability samples characterize an anomalously low period of ^7Be deposition during this study (i.e. drought conditions). Under these conditions the dry deposition of ^7Be would become the primary source to the basin, and this scenario is certainly not typical for this sub-tropical environment.

Deposition Rates

Seasonal deposition rates for both stations are listed in Table 2 and shown graphically in Figure 8. As described above, these rates are calculated by dividing the new inventory of ^7Be by the mean surface activity of ^7Be , which yields mass deposition (i.e. g cm^{-2}). This method of calculating sedimentation rates was used so that short-term (monthly) rates could be quantified. The variability in delivery and sparse number of data points prohibits using the slope of the regression technique (i.e. ^7Be activity against depth). Furthermore, as Canuel et al., 1990 point out, the regression method would calculate a sedimentation rate that integrates over approximately a year and therefore would yield rates even during times of net sediment erosion at a given site.

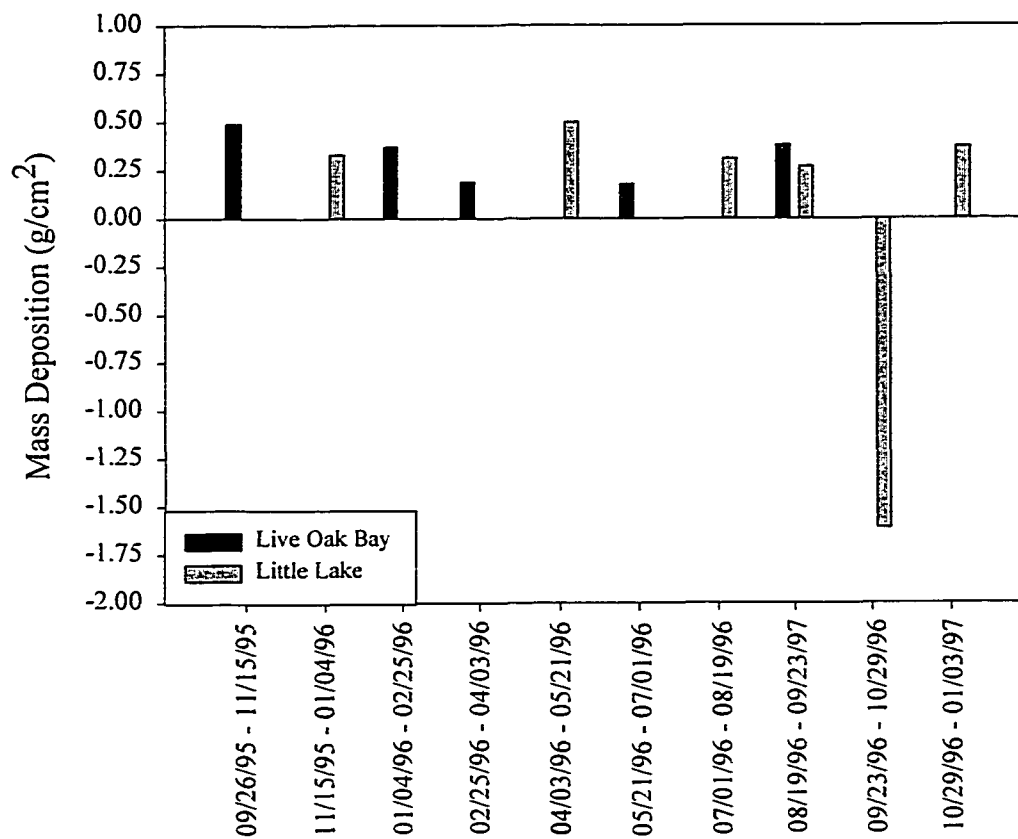


Figure 1.8. Bulk particulate deposition rates at Little Lake and Live Oak Bay.

During the present study sediment transport at the LLN station appears to be most active during the spring, summer and early fall months. This is likely due to the orientation of this location with respect to the direction and strength of the winds occurring during these seasons. The LOB station exhibits active sediment transport throughout the year. This is likely due to the fact that this station is located adjacent to the wetland interface. Highest rates of deposition occurred during fall and winter months and are likely due to the flushing of material out of the marshes in response to cold front passages.

Burial Rates

Burial rates reported here are several times lower than previous studies have indicated (Stowe et al., 1985; Feijtel et al., 1988). This difference may be real but is likely due in part to the different methods that were applied to obtain sedimentation rates. The previous studies have applied the marker horizon technique utilizing the down core distribution of ^{137}Cs . This technique works well in rapidly accumulating marsh deposits (Delaune et al., 1978). However, in unvegetated subaqueous bottom sediments, surface sediment mixing processes decrease the effectiveness of this technique by obscuring the subsurface maximum in concentration. Additionally, this marker horizon technique does not discern layers of mixed sediments or storm deposits and therefore would tend to overestimate sedimentation rates.

Sedimentation rates reported in this work are maximum rates, due to the assumption that radioactive decay is the only mechanism acting to reduce excess ^{210}Pb activity below any surfaced mixed layer. Long-term rates of sediment

transport follow intuitive expectations in that stations located proximal to the marsh interface have the highest rates. Whereas, cores collected from environments not directly influenced by the marsh interface have the lowest rates of burial. The burial core collected at the LOB station indicates that surface mixing is minimal at this station for the long-term (Figure 9). Therefore, based on the burial rate (0.18 cm/yr) and the sampling interval (1 cm), it appears that burial rates are controlled by processes acting on a time scale of approximately 6 years. The frequency of hurricanes affecting the Barataria Basin has been estimated at one every 8 years (Madden and Day, 1988). Therefore, it is likely that the occurrence of hurricanes and tropical storms is the controlling process for long-term sediment accumulation in subaqueous bottom sediments of the Barataria Basin.

CONCLUSIONS

The atmospheric delivery of ^7Be to the Barataria Basin was maximal during summer months and minimal during fall and winter months. This is likely due to differences in the depositional characteristics of the precipitation that occurs during these seasons. The annual atmospheric flux of ^7Be was quantified at two stations (~10 km apart) and ranged from 24.0 to 26.0 dpm cm^{-2} (daily fluxes ranged from 0.02 – 0.16 dpm cm^{-2}). The variability in annual fluxes indicates that it is important to quantify atmospheric depositional inputs locally when considering atmospheric fluxes to specific aquatic systems.

The seasonal sediment transport within the basin was variable, ranging from $-1.6\text{E}3$ to $1.42\text{E}4 \text{ g m}^{-2} \text{ yr}^{-1}$, and likely controlled by seasonal wind conditions and the

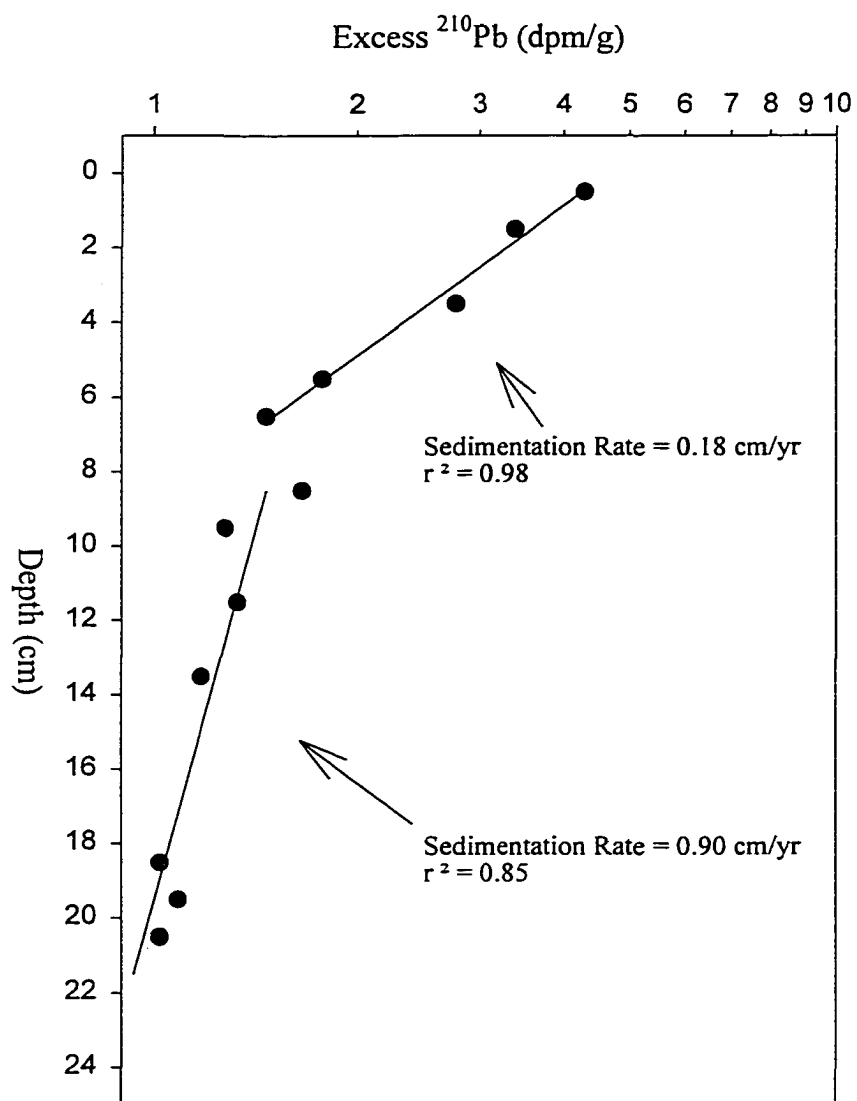


Figure 1.9. Down-core excess ²¹⁰Pb activity and sedimentation rates at Live Oak Bay.

orientation of the local environment to these winds. Locations most vulnerable to seasonal wind conditions are the central portions of bays and lakes. At these locations both short and long term sedimentation rates may be controlled by seasonal wind patterns (i.e. short-term rates are approximately equal to long-term rates). In contrast, locations proximal to the marsh interface exhibit short term rates of deposition several times higher than the long term burial rate. At these locations short-term sedimentation is enhanced by frontal passages occurring in the fall and winter.

Burial rates for subaqueous bottom sediments in the Barataria Basin ranged from 0.08 to 0.25 cm yr⁻¹. In general, cores collected from sites which were proximal to wetland vegetation and more sheltered had the highest sedimentation rates. The average burial rate for the more protected sites was 0.21 cm yr⁻¹, while the average burial rate for the less protected sites was 0.11 cm yr⁻¹. Burial rates appear to be controlled on a time scale that closely resembles the frequency of hurricanes impacting the basin.

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CHAPTER 2

DEPOSITION AND BURIAL OF PARTICULATE ORGANIC CARBON WITHIN SUBAQUEOUS BOTTOM SEDIMENTS IN THE BARATARIA BASIN, LA

INTRODUCTION

Globally, ocean margins comprise approximately 8% of the surface area of the ocean (Wollast, 1991) and include estuarine, coastal, and shelf components (Mantoura et al., 1991). In the marine biogeochemical cycles of the elements, coastal margins serve to filter the input of continentally derived material, thereby influencing terrestrial and anthropogenic fluxes to the ocean. It is estimated that these environments account for 20 to 30% of ocean productivity (Wollast, 1981; Berger, 1989; Wollast, 1991), and retain approximately 90% of riverine particulates, and the associated trace elements and pollutants (Martin and Windom, 1991; Milliman, 1991). River dominated coastal margins (RioMar's) have unique characteristics which make them important for advancing the understanding of global biogeochemical cycles. These characteristics include (i) direct input of riverine dissolved and particulate loads, (ii) the highest levels of primary productivity in the oceans, (iii) high sedimentation rates, and (iv) intensive diagenetic processes due to the availability of metal oxides and frequent reworking of bottom sediments. It has been shown that the majority (> 90%) of elements and nutrients transported in global rivers arrive at coastal margins in the particulate phase (Meybeck, 1982; Martin and Whitfield, 1983). Therefore, processes affecting the subsequent transport and fate of these coastal margin sediments can have a profound

effect on global biogeochemical cycles. For example, recent work in river dominated coastal environments indicates that post depositional processes, occurring in deltaic sediments, can significantly alter (i.e. decrease by 30 to 50%) the riverine particulate concentration for elements such as uranium and organic carbon, thereby potentially increasing the non-particulate phase flux to the ocean for these important elements (McKee et al., 1996; Aller et al., 1998). The degree to which this occurs globally will directly impact global biogeochemical budgets. Nonetheless, the importance of coastal margins in global biogeochemical cycles remains poorly understood (Mantoura et al., 1991).

An important component of the river dominated coastal margin is the estuary. Shallow, turbid estuaries are known to be more productive due to a well mixed water column with sufficient light and nutrients (Boynton et al., 1982; Kemp and Boynton, 1984; Day et al., 1989). These environments are potentially important reservoirs in the global carbon cycle due to an abundant supply of organic carbon (allochthonous input of terrigenous carbon and autochthonous input of marine carbon), and high rates of sedimentation which may serve to increase the burial efficiency of organic carbon.

Tropical and subtropical regions of the globe (i.e. between 30°N and 30°S) contain approximately 30% of ocean margins (Alongi, 1998), and receive greater than 80% of the annual riverine flux of sediments to the ocean (Milliman, 1991). Therefore, knowledge of tropical and subtropical estuarine dynamics is critical for understanding global biogeochemical budgets. However, much of our paradigm for

how estuaries process materials is based on studies of temperate coastal environments (Nixon, 1981; Nixon and Pilson, 1983; Kemp and Boynton, 1984; Peterson and Howarth, 1987; Canuel and Martens, 1996). Fundamental differences exist between these coastal environments that directly affect the way in which tropical and subtropical estuaries process materials in comparison to temperate estuaries (Day et al., 1989; Alongi, 1998).

In the subtropical, northern Gulf of Mexico, shallow, highly productive estuaries are common and largely due to riverine input and a low energy coastal regime (Schroeder and Wiseman, 1999). The objective of this paper is to quantify monthly and decadal rates of organic carbon deposition and burial in bottom sediments in a typical, shallow northern Gulf of Mexico estuary: Barataria Basin, Louisiana.

Background

Estuaries are some of the most productive natural environments in the world (Day et al., 1989). Some fraction of the carbon produced in estuaries is exported to the adjacent coastal ocean where it serves to increase the metabolism of offshore waters (Madden et al., 1988). Odum, 1971 called this phenomenon "outwelling". Previous studies have investigated the distribution and transport of organic carbon in the Barataria Basin (Day et al., 1973 and 1983; Happ et al., 1977; Smith et al., 1983; Feijtel et al., 1985). The primary goal of these studies was to determine the role that the Barataria plays as a source or sink for organic carbon in the marine carbon cycle. Early work characterizing aquatic primary production in the Barataria reported that the upper basin was heterotrophic and eutrophic, that the degree of heterotrophy

decreased in a down basin direction, and that the lower basin was slightly autotrophic (Day et al., 1977 and 1982). Early work on carbon flow in the Barataria Basin estimated, based on a mass balance approach, that the basin produced approximately $150 - 300 \text{ g C m}^{-2} \text{ yr}^{-1}$ that was available for export to the adjacent Gulf of Mexico and/or burial in bottom sediments (Day et al., 1973; Happ et al., 1977). These studies also indicated that this carbon likely originated from salt marshes fringing the lower basin. Feijtel et al., 1985 refined this estimate by including burial in subaqueous sediments and CO_2 and CH_4 emission from marsh sediments, and indicated that the amount of organic carbon available for export ranges between 150 and $250 \text{ g C m}^{-2} \text{ yr}^{-1}$. Carbon isotope ($^{13}\text{C}/^{12}\text{C}$) information, expressed as $\delta^{13}\text{C}$ (‰), can provide insight for determining the source of the particulate organic carbon (POC) in aquatic environments due to differences in isotope fractionation by C_3 and C_4 plant species during photosynthesis. The Barataria Basin displays a vegetational gradient with C_3 plants dominating in the freshwater marshes in the upper basin and C_4 species dominating in the salt marshes of the lower basin (Chmura et al., 1987). C_3 plants have $\delta^{13}\text{C}$ values which range from -23 to -34 ‰, while C_4 plants have $\delta^{13}\text{C}$ values range between -9 to -17 ‰ (Smith and Epstein, 1971). Previous studies have measured the $\delta^{13}\text{C}$ values for marsh plants and surface marsh sediments from various locations throughout the Barataria Basin (Chmura et al., 1987; Delaune and Lindau, 1987). These studies found that surface sediment $\delta^{13}\text{C}$ values from freshwater marshes (-27.8 to -26.6 ‰) closely approximated the value expected from whole plant material (-27.8 to -26.3 ‰), while

surface sediment $\delta^{13}\text{C}$ from brackish marshes (-14.9 ‰) was depleted relative to whole plant material (-13.0 ‰) as was surface sediment values from saline marshes (-16.0 ‰) in comparison to whole plant material (-13.3 ‰). The discrepancy between surface sediment and whole plant $\delta^{13}\text{C}$ values for brackish and salt marsh environments was attributed to the decomposition of whole plant material (Chmura et al., 1987). Delaune and Lindau, 1987 reported that the $\delta^{13}\text{C}$ signature of subaqueous bottom sediments was also depleted in comparison to whole plant values in brackish and saline environments. They also observed that $\delta^{13}\text{C}$ values in saline marsh environments became progressively depleted with increasing distance from the marsh interface, and suggested that organic carbon inputs from *in situ* production become dominant in central portions of large water bodies (i.e. marine carbon $\delta^{13}\text{C}$ values range from -21 to -19 ‰).

STUDY AREA

General Description

The Barataria Basin is an intertributary estuarine-wetland system located in southeast Louisiana (Fig. 1). It is bordered on the north and east by the Mississippi River and on the west by Bayou Lafourche. The basin has a total area of approximately 628,000 hectares (ha), including 202,000 ha of open water and 206,000 ha of marsh (Fig. 2; Conner and Day, 1987). Dominant morphological features include levees (natural and artificial), canals, bayous, bays, lakes, swamp and marsh wetlands, and barrier islands (Conner and Day, 1987). The Barataria estuary may be characterized as a bar-built lagoon; it is shallow with sandbars at the



Figure 2.1. Location of the Barataria Basin with major water bodies identified.

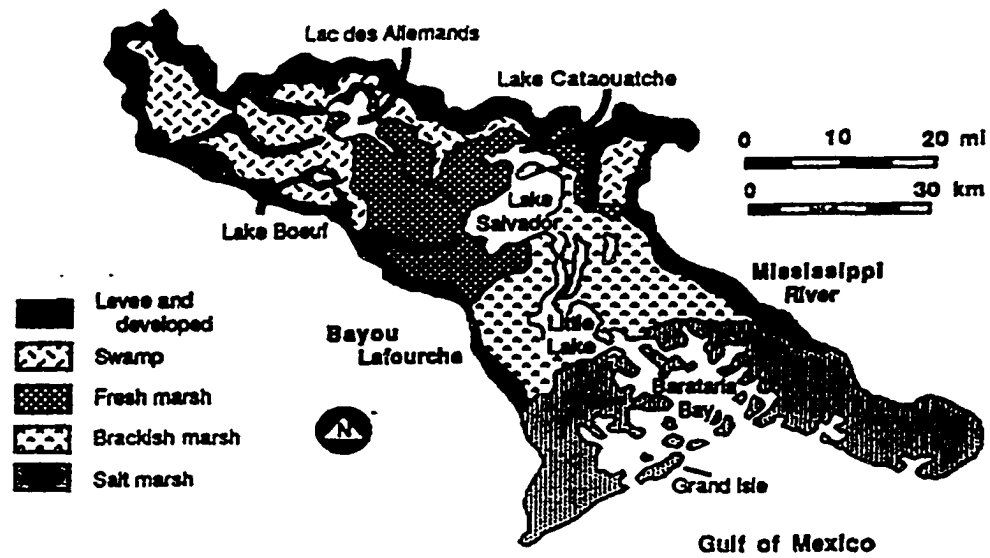


Figure 2.2. Habitat map of the Barataria Basin (from Conner and Day, 1987).

mouth and has a small tidal range (Adams et al., 1976). The average depth of open water bodies is approximately 2 meters (Conner and Day, 1987). Tides in the basin are diurnal with an average range of 32 cm at the coast (Baumann, 1987). On average, coastal Louisiana receives about 160 cm of precipitation annually (Baumann, 1987). Presently, the basin is experiencing reduced freshwater input (due to leveeing of the Mississippi River and surrounding waterways), increasing salinity and wetland erosion, resulting in a rapid transition back to an open marine environment (Madden et al., 1989).

Hydrology

The Barataria Basin is a meteorologically forced, micro-tidal estuary (Boesch et al., 1989). Water movement through the basin is a function of tidal influence, winds and precipitation. The combination of these influences creates slow moving bayous and promotes sheet flow over the wetlands (Conner and Day, 1987). Seasonal water level in the basin exhibits a bimodal distribution with maximum water levels occurring in the spring, due to precipitation and runoff, and summer, due to an expanding Gulf water mass (Baumann, 1987). The spring peak is discernable but considerably attenuated for locations in the lower basin. This is attributed to a decreased upland runoff influence (marine dominance) for the lower basin (Baumann, 1987).

The natural hydrology of the basin has been altered extensively by human activities such as, channel dredging and levee construction (Turner and Cahoon, 1988). For example, leveeing of the Mississippi River has effectively eliminated the

major fluvial input of freshwater and sediments to the basin. Precipitation is now the primary source of freshwater. Linear canals dredged to depths greater than the surrounding bay bottoms promote the intrusion of high salinity water into the interior basin, and also provide efficient conduits for the transport of materials out of the basin (Madden et al., 1988). The overall effect of these activities has been to decrease the transfer of sediments to the marsh surface, thereby decreasing the sustainable marsh area of the basin.

Material Transport

The transfer of material (e.g. sediments, organic matter and nutrients) within the basin depends on water movement. Before the river was leveed, the bulk of material transport occurred in the spring in relation to the annual Mississippi River flood. Presently, maximum water exchange in the Barataria occurs in the fall and winter in response to the passage of cold fronts (Baumann, 1987; Madden et al., 1988). During these seasons an average of approximately 5 frontal passages occur per month (Baumann, 1987). As a cold front approaches the coast, southerly component winds strengthen and push water into the basin, flooding the marshes. After the front passes, northerly component winds become dominant and push the water out of the basin, draining the marshes. Water level variability in the marsh approaching 1 m d^{-1} has been documented in relation to wind stress (Muller, 1979). This scenario is repeated for each frontal passage and has been shown to be important for material transport in the basin (Baumann et al., 1984; Rovaneck, 1997). Storm passages are now the only mechanism that transports sediments to the surface

of the marsh. A study of the seasonality of marsh accretion indicates that as much as 75% of the annual accretion results from winter storm passages, in years when tropical storms did not impact the basin (Baumann et al., 1984). The source of these sediments is primarily resuspended bottom sediments from lakes and bays (Madden et al., 1988).

Sampling Sites

Samples were collected in brackish (Little Lake and Lake Salvador) and saline (Live Oak Bay, Barataria Bay, Bay Batiste, Bay Desllettes, Caminada Bay) environments (Fig. 3). Sediment grain size, of surface bottom sediments, varies from clayey sand to sand-silt-clay in the areas where samples were collected from the lower basin (Flowers et al., 1995). Samples for seasonal deposition were collected in Little Lake and Live Oak Bay. Little Lake is shallow (~ 1.5 m) and moderately productive for coastal Louisiana ($1307 \text{ g O}_2 \text{ m}^{-2} \text{ yr}^{-1}$) with a salinity range of 0 – 15 (Madden et al., 1989 and references therein). Bayou Perot, which empties into the northern end of Little Lake, provides a direct connection to Lake Salvador, the largest water body in the middle basin. Generally, from Lake Salvador south the waters of the basin receive less anthropogenic nutrients and are representative of a natural environment responding to decreased river influence, with respect to nutrient dynamics and primary productivity (Madden et al., 1989). Live Oak Bay is a small embayment located on the western side of Barataria Bay; which is one of the primary water bodies making up the basin's estuary. Live Oak Bay is

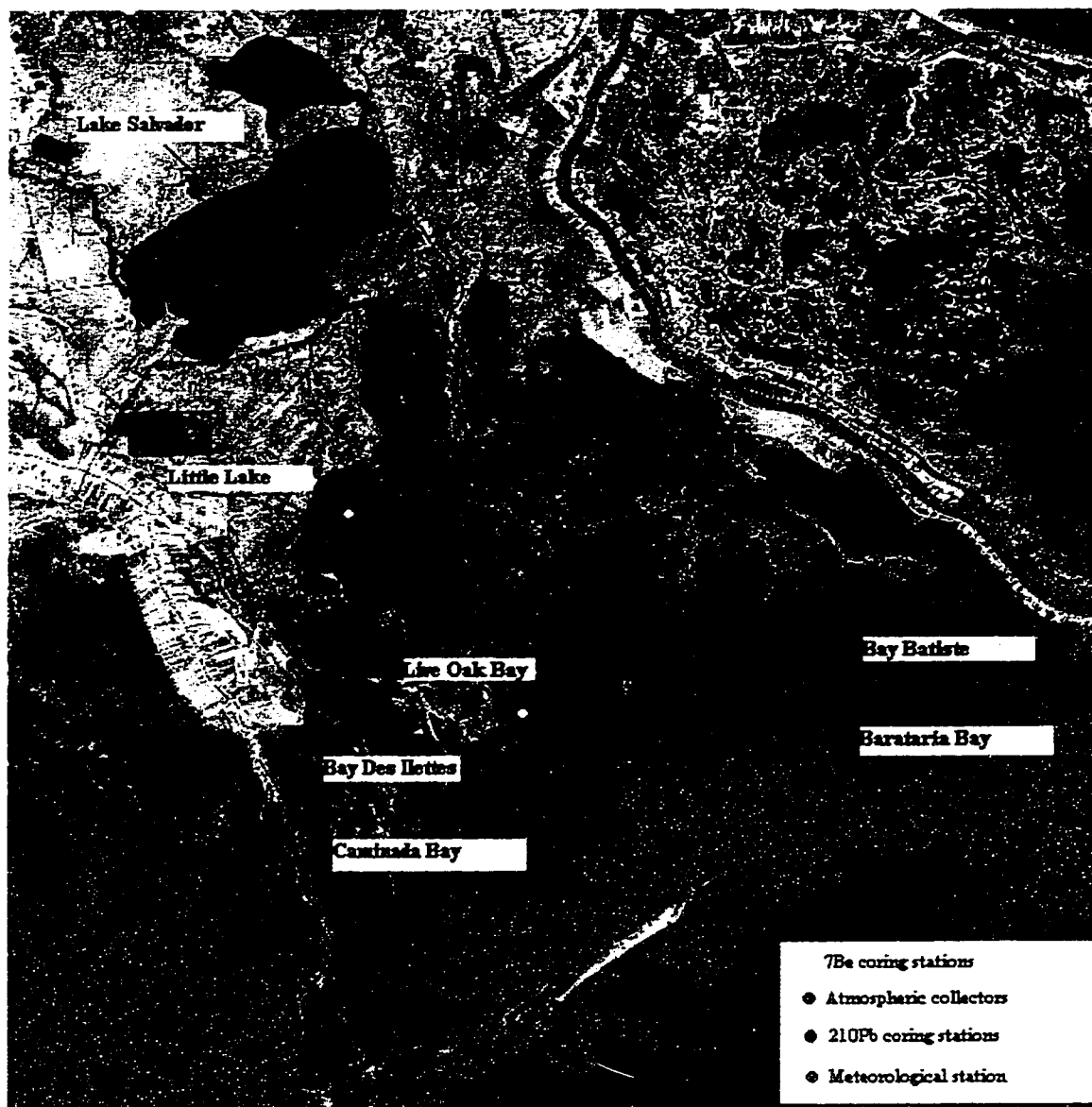


Figure 2.3. Locations of bottom sediment sampling sites.

shallow (~ 1 m) with a clayey-silt substrate. A bayou draining the surrounding marsh (*spartina alterniflora*) empties into the northern end of Live Oak Bay. Material transport in the bayou has been shown to be dominated by cold front passages and tropical storms (Rovansek, 1997).

METHODS

Bottom Sediment Collection

Sediment cores were gathered from a small boat with a hand-held PVC coring device. The core tube was gently pushed into the bottom sediments to obtain a vertical column of sediment. Cores for short-term deposition were collected at 4 to 6 week intervals from two locations, Live Oak Bay and Little Lake, for the duration of the study (Figure 3). These sediments were immediately extruded and subsectioned to a depth of 5 cm. The top 1 cm was sampled at 0.5 cm intervals and thereafter 1 cm intervals were collected. Nine cores were collected throughout the basin in the same manner as above to determine long term rates of sediment and organic carbon burial (Fig. 3). These cores were extruded at 1-cm intervals to depths ranging from 20 to 30 cm. Aliquots for POC analyses were collected for all of the above sediment samples. POC subsamples were placed into polycarbonate centrifuge tubes and stored on ice for transport to the laboratory.

Radiochemical Techniques

A summary of the radiochemical techniques applied for determining sediment and organic carbon geochronologies is provided below. A detailed description of these techniques is provided in Booth et al., 1999a.

Sediment burial rates were determined by quantifying excess ^{210}Pb activity via its Polonium (^{210}Po) daughter. Particulate material (1 to 3 g) was spiked with the yield tracer ^{209}Po and leached in a commercial microwave digestion system (CEM-MDS-81D). Following auto-deposition onto silver planchets for 48 to 72 hours, each planchet was analyzed for ^{209}Po and ^{210}Po activity by alpha spectroscopy using *Canberra* Quad and *Ortec* Octet detector configurations (Si-surface barrier detectors). Each sample was counted for approximately 48 hours or until an appropriate amount of counts were acquired to insure sufficient accuracy and precision.

Sediment deposition rates were determined from surficial bottom sediment inventories of ^7Be activity. ^7Be activities were quantified using gamma ray spectroscopy (intrinsic germanium, planar type detector) and multi-channel analyzer. Counting efficiencies were determined by placing a mixed gamma source (IAEA-300, Black Sea sediments) into a petri dish (50 mm x 9 mm) and quantifying gamma emitters over a range of energies (46.5 – 1460 KeV). Linear interpolation between the ^{214}Pb peak at 351.9 KeV and the ^{214}Bi peak at 609.3 KeV was used to quantify the counting efficiency for ^7Be centered at 477.6 KeV. The activity of ^7Be in each sampling period was decay corrected to the mid-point of the sampling period using the $C = C_0 e^{-\lambda t}$ relationship where “t” equals one-half the number of days in each sampling period. Inventories were calculated using

$$I (\text{dpm/cm}^2) = X_i (1 - \phi) (\rho_s) (A_i), \quad (1)$$

where X_i is the sample interval thickness (cm), ρ_s is the dry particle density (g cm^{-3}), A_i is the activity of ^7Be (dpm g^{-1}) and ϕ is the bottom sediment porosity where $\phi = (w_2 - w_3/\rho_w) / [(w_2 - w_3/\rho_w) + (w_3 - w_1/\rho_s)]$, where w_1 is the container weight (g), w_2 is the wet sediment weight (g), w_3 is the dry sediment weight (g), ρ_w is the density of water (1.01 g cm^{-3}) and ρ_s is the density of sediments (2.5 g cm^{-3}).

Total bottom sediment ^7Be inventories were separated into two components, residual inventory and new inventory, after the technique presented by Canuel et al., 1989. The residual inventory accounts for the ^7Be inventory from the previous sampling period, decay corrected to the subsequent sampling period. The difference between the total inventory and the residual inventory represents the new inventory, which accounts for material deposited to the site during the time between sample collection. Short-term sediment deposition rates were calculated by dividing the new inventory (dpm/cm^2) by the mean new activity (dpm/g) yielding mass deposition (g/cm^2).

Particulate Organic Carbon Concentrations

Sediment aliquots described above were dried at $\sim 60^\circ \text{C}$ overnight and ground using a mortar and pestle. The sediments were soaked in dilute HCL acid (10%) overnight to remove any inorganic carbon. The samples were dried and ground again, and 20 mg aliquots (i.e. duplicates) analyzed for particulate organic carbon and nitrogen using a CE Instruments Elemental Analysis System (Model NC 2500). Instrument performance was monitored by measuring standards after every

10 samples, and the accuracy maintained at $\pm 2\%$ of the standard. Duplicate sample performance was maintained at $\pm 5\%$.

Deposition and Burial Rates for POC

Deposition rates for POC were calculated by multiplying the particle deposition rate ($\text{g m}^{-2}\text{d}^{-1}$) by the mean POC concentration (g C/ g sediment) of the inventory, yielding $\text{g C m}^{-2} \text{d}^{-1}$ for monthly rates, and by summing these monthly rates to obtain an annual deposition rate ($\text{g C m}^{-2} \text{yr}^{-1}$). Burial rates were determined by calculating the mean concentration of POC in the region of the core where excess ^{210}Pb activities exhibited a linear decrease with depth. The burial rate ($\text{g m}^{-2} \text{yr}^{-1}$) was then multiplied by this mean value for POC, yielding $\text{g C m}^{-2} \text{yr}^{-1}$.

RESULTS

Deposition Samples

Surface sediment profiles of POC (%) and C/N at Little Lake and Live Oak Bay are depicted in Figures 4 and 5. Generally, POC concentrations were higher and less variable at Live Oak Bay (avg. = $7.4 \pm 1.6\%$, $n = 57$) compared to Little Lake (avg. = $5.4 \pm 1.7\%$, $n = 36$). Monthly POC deposition rates ranged from 2.9 to $8.6 \text{ g C m}^{-2} \text{d}^{-1}$, with an annual rate of $1066 \pm 517 \text{ g C m}^{-2}$ at the Live Oak Bay station, and from -23.4 to $6.4 \text{ g C m}^{-2} \text{d}^{-1}$, with an annual rate of $122 \pm 545 \text{ g C m}^{-2}$ at the Little Lake site (Table 1).

Burial Samples

Bulk particulate and POC burial data from 9 cores collected in the Barataria Basin are listed in Table 2. POC burial rates ranged from 8 to $37 \text{ g C m}^{-2} \text{yr}^{-1}$. In

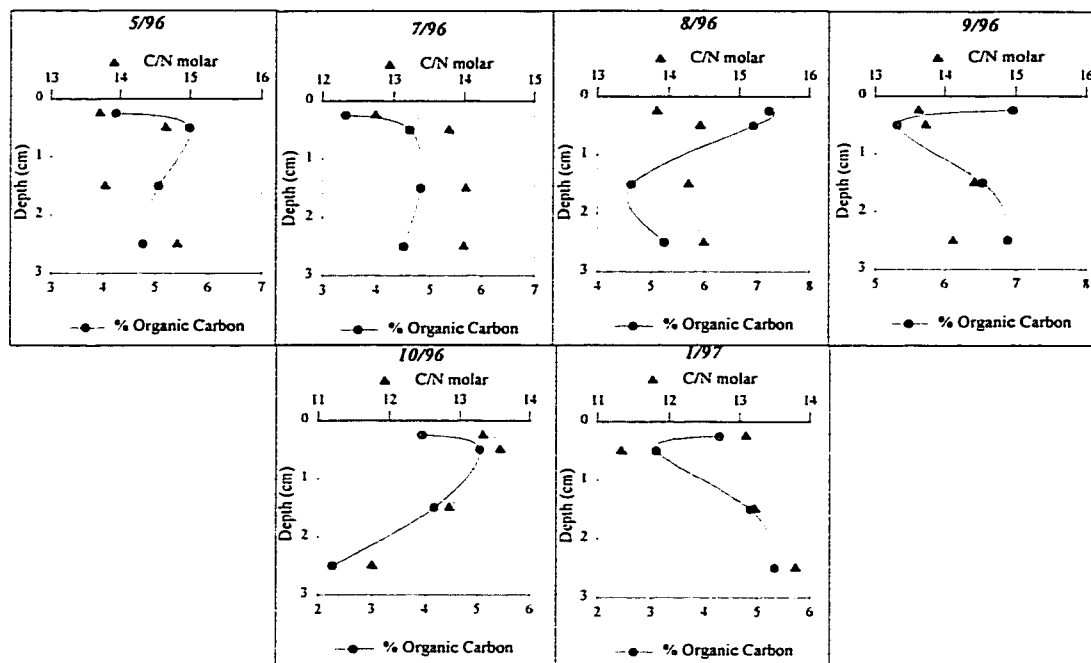


Figure 2.4. POC and C/N values for deposition cores from Little Lake.

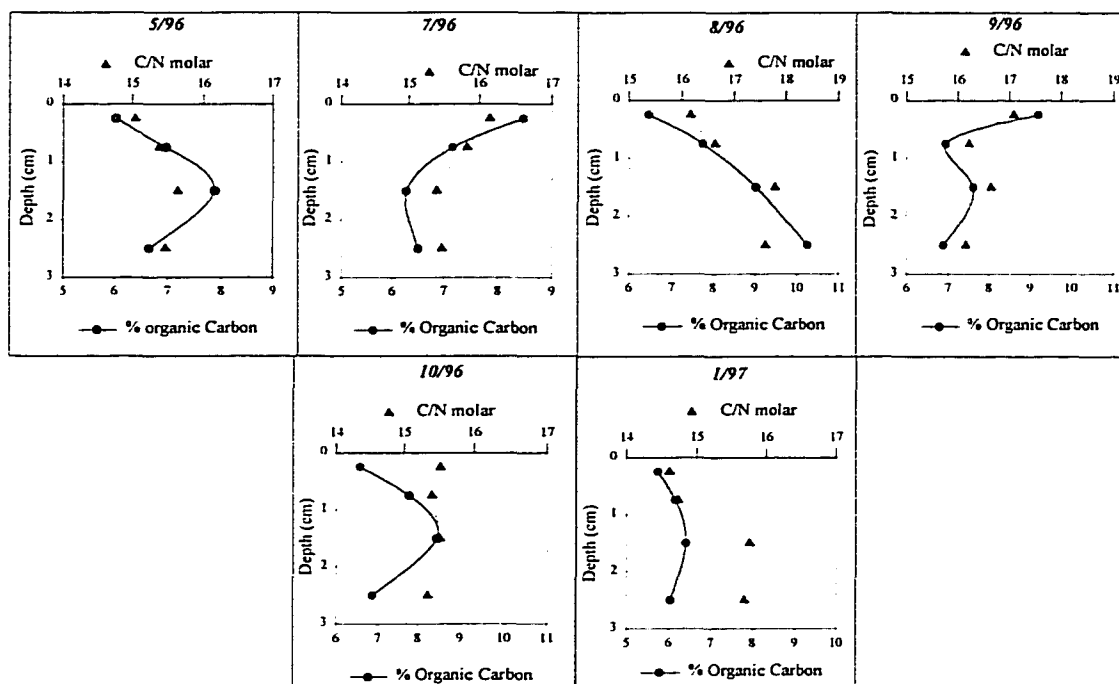


Figure 2.5. POC and C/N values for deposition cores from Live Oak Bay.

general, cores collected from sites that were proximal to wetland vegetation had the highest POC burial rates (e.g. Live Oak Bay, Bay Batiste and Caminada Bay). The average POC burial rate for the sites adjacent to the marsh interface is $30 \pm 7.5 \text{ g C m}^{-2} \text{ yr}^{-1}$ ($n = 3$), while the average burial rate for the stations removed from any direct influence of the marsh is $15.5 \pm 6.3 \text{ g C m}^{-2} \text{ yr}^{-1}$ ($n = 6$).

DISCUSSION

Particulate Organic Carbon Deposition

The transport of particulate material at a given location in the Barataria Basin is primarily determined by the dominant wind characteristics and the orientation of the local environment to these winds (Booth et al., 1999b). Little Lake is a large water body ($\sim 100 \text{ km}^2$) that experiences significant bottom sediment resuspension throughout the year, while Live Oak Bay, due to its small size ($\sim 1 \text{ km}^2$) likely is only partially resuspended during the cold front season (i.e. fall and winter) (Booth et al., 1999b). In addition to local resuspension, Little Lake receives inputs of suspended particles from Lake Salvador (during northerly dominant wind events) and from the lower basin (during southerly dominant wind events). Live Oak Bay receives inputs of suspended particles from a bayou on the northern edge of the bay that drains the surrounding salt marsh.

Seasonal characteristics of bottom sediment organic carbon deposition at Little Lake and Live Oak Bay are listed in Table 1. The largest deposition rate at Little Lake occurred in conjunction with a shift, from northerly to southerly, in the dominant wind direction (Table 1). Therefore, due to the prevailing southerly winds,

Table 2.1. Bottom sediment ^7Be inventories, ^7Be surface activities, bulk particulate and POC mass deposition rates at Little Lake and Live Oak Bay.

Live Oak Bay					
Sample ID	Total	New	Average ^7Be	Mass	POC
	Inv. (dpm cm^{-2})	Inv. (dpm cm^{-2})	Act. (dpm g^{-1})	Dep. (g cm^{-2}) ⁴	Dep. (g C $\text{m}^{-2} \text{d}^{-1}$)
09/26/95	4.97 (± 2.14) ¹				
11/15/95	8.76 (± 3.77)	6.17 (± 3.93)	12.59 (± 0.64)	0.49 (± 0.31)	7.5 (± 4.7)
01/04/96	7.12 (± 3.06)	2.54 (± 3.64) ³	9.98 (± 0.69)		
02/25/96	10.26 (± 4.41)	6.64 (± 4.68)	17.76 (± 1.43)	0.37 (± 0.26)	5.4 (± 3.8)
04/03/96	11.80 (± 5.07)	5.54 (± 5.74) ³	28.8 (± 1.80)		
05/21/96	5.83 (± 2.51)	(-)1.29 (± 3.95) ³	0.00		
07/01/96	8.33 (± 3.58)	5.17 (± 3.83)	28.77 (± 2.75)	0.18 (± 0.13)	2.9 (± 2.1)
08/19/96	6.47 (± 2.78)	1.51 (± 3.50) ³	19.97 (± 2.27)		
09/23/96	9.56 (± 4.11)	5.66 (± 4.43)	14.86 (± 2.24)	0.38 (± 0.29)	8.6 (± 6.5)
10/29/96	8.94 (± 3.84)	2.88 (± 4.64) ³	16.93 (± 2.24)		
01/03/97	6.38 (± 2.74)	2.54 (± 3.20) ³	23.36 (± 1.51)		
			Total Dep. =	1.42 (± 0.68) ⁵	1066 (± 517) ⁶
Little Lake					
Sample ID	Total	New	Average ^7Be	Mass	POC
	Inv. (dpm cm^{-2})	Inv. (dpm cm^{-2})	Act. (dpm g^{-1})	Dep. (g cm^{-2}) ⁴	Dep. (g C $\text{m}^{-2} \text{d}^{-1}$)
11/15/95	6.54 (± 2.68) ²		6.43 (± 0.39)		
01/04/96	6.16 (± 2.53)	2.75 (± 2.89) ³	8.32 (± 0.37)		
02/25/96	4.80 (± 1.97)	1.67 (± 2.35) ³	3.28 (± 0.39)		
04/03/96	0.00	(-) 2.93	0.00		
05/21/96	2.33 (± 0.96)	2.33 (± 0.96)	4.64 (± 0.81)	0.50 (± 0.21)	6.4 (± 2.7)
07/01/96	1.82 (± 0.75)	0.44 (± 0.94) ³	8.64 (± 0.51)		
08/19/96	12.03 (± 4.93)	11.07 (± 4.95)	35.3 (± 3.51)	0.31 (± 0.14)	4.3 (± 1.9)
09/23/96	19.52 (± 8.00)	11.88 (± 8.59)	43.7 (± 4.05)	0.27 (± 0.20)	3.8 (± 2.8)
10/29/96	3.26 (± 1.34)	(-) 8.80 (± 5.13)	5.48 (± 0.94)	(-)1.61 (± 0.94)	(-) 23.4 (± 13.6)
01/03/97	6.98 (± 2.86)	5.58 (± 2.92)	14.96 (± 1.72)	0.37 (± 0.19)	2.8 (± 1.4)
			Total Dep. =	(-)0.16 (± 1.01) ⁷	122 (± 545) ⁸
¹ Errors based on Coefficient of Variability (0.43) from spatial data					
² Errors based on Coefficient of Variability (0.41) from spatial data					
³ Associated error larger than measurement so assumed no net deposition or removal					
⁴ Net particle deposition since preceeding sample date					
⁵ Total particle deposition from 9/95 to 9/96					
⁶ Total particulate organic carbon (POC) deposition from 9/95 to 9/96					
⁷ Total particle deposition from 1/96 to 1/97					
⁸ Total particulate organic carbon (POC) deposition from 1/96 to 1/97					

late spring and summer were the most important seasons for POC deposition at Little Lake (Table 1). The characteristics (i.e. average POC content = 5% and average C/N value = 13.6) of sedimentary organic carbon from Little Lake indicate that allochthonous sources are dominant (Figure 4). However, an increase in the POC content, from approximately 4% to more than 6% during the summer months may be indicative of benthic productivity in response to less turbid water conditions (Madden et al., 1988). In contrast, at Live Oak Bay deposition occurs primarily in the fall and winter in conjunction with cold front passages (Table 1). The characteristics (i.e. average POC content = >7% and average C/N value = 16) of sedimentary organic carbon from Live Oak Bay also indicate that allochthonous carbon sources are dominant (Figure 5).

Particulate Organic Carbon Burial

Burial rates reported in this work are maximum rates, due to the assumption that radioactive decay is the only mechanism acting to reduce excess ^{210}Pb activity below any surfaced mixed layer. Based on surface sediment C/N values from freshwater (Lake Salvador C/N = ~ 12), brackish (Little Lake C/N = ~ 14) and saline (Live Oak Bay C/N = ~ 16) environments it appears that allochthonous carbon sources are important throughout the basin. Generally, POC burial rates are highest at locations proximal to the marsh interface, with an average rate of $30 \pm 7.5 \text{ g C m}^{-2} \text{ yr}^{-1}$ ($n = 3$), while the average burial rate for locations removed from any direct influence from the marsh is $15.5 \pm 6.3 \text{ g C m}^{-2} \text{ yr}^{-1}$ ($n = 6$). Sediment cores from Lake Salvador indicate that approximately $15 \text{ g C m}^{-2} \text{ yr}^{-1}$ is buried (Table 2). As a

Table 2.2. Bulk particulate and POC burial rates in the Barataria Basin.

Location	Latitude	Longitude	¹ Bulk particulate burial (cm yr ⁻¹)	¹ Bulk particulate burial (g m ⁻² yr ⁻¹)	POC burial (g C m ⁻² yr ⁻¹)
Lake Salvador	29° 47.00	90° 11.15	0.09	3.83E+02	13.5
Lake Salvador	29° 44.00	90° 14.00	0.14	7.35E+02	17.0
Lake Salvador	29° 42.30	90° 20.00	0.13	8.45E+02	15.0
Little Lake	29° 32.48	90° 10.59	0.12	6.90E+02	27.0
Bay Batiste	29° 27.47	89° 50.53	0.19	1.05E+03	31.0
Live Oak Bay	29° 24.14	90° 03.57	0.18	7.20E+02	37.0
Barataria Bay	29° 23.00	89° 56.48	0.08	6.60E+02	8.0
Bay Des Illetes	29° 18.59	90° 01.00	0.12	9.00E+02	13.0
Caminada Bay	29° 14.59	90° 04.58	0.25	2.00E+03	22.0
¹ Burial rate is a maximum (i.e. assumes mixing below surface mixed layer is negligible)					

comparison, POC burial on the adjacent Louisiana Shelf has been shown to range between > 450 to $30 \text{ g C m}^{-2} \text{ yr}^{-1}$, with an area-weighted average of $64 \text{ g C m}^{-2} \text{ yr}^{-1}$ (McKee and Twilley, 1999). Surface sediment POC content ranges from 2.5 to 5.0% and exhibits progressive depletion with depth due to oxidative breakdown of organic matter (Figs. 6 - 8). Sediments are primarily transported into Lake Salvador from Lake Des Allemands, a freshwater swamp environment, and from the Inter-Coastal Waterway, which transports turbid Atchafalaya River water under certain river discharge and wind conditions. A station in Lake Salvador (Core 2) which is directly influenced by input from the Inter-Coastal Waterway exhibited the highest POC content (5 %) and C/N value (~ 12) for surface sediments and the most extensive depletion, to approximately 1 % with a C/N value of 7, at depth (Fig. 7). This same scenario is exhibited at the Little Lake station (Fig. 9) which also receives input from the Inter-Coastal Waterway via Bayou Perot (Fig. 3). These locations exhibit the most intensive and complete diagenetic breakdown of organic matter for all sediment cores examined in this study. One possible explanation for this occurrence is that the input of organic matter is accompanied by the presence of inorganic sediment (from the Atchafalaya River discharge) with metal oxyhydroxide coatings, such as Fe and Mn, that may contribute to the more efficient oxidation of organic matter. In contrast to these stations is the Live Oak Bay site, which also exhibits high POC contents (i.e. surface values ~ 5 %) and high C/N values (~ 14) but

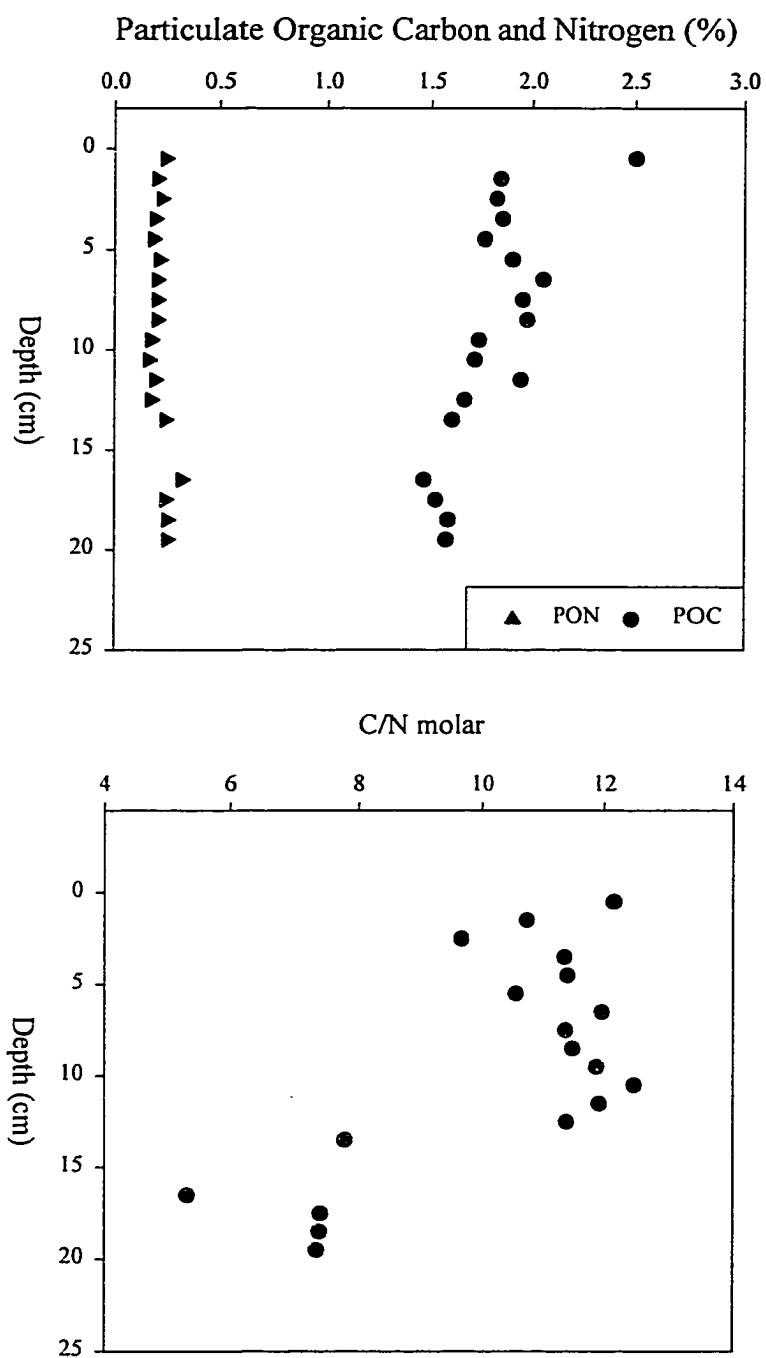


Figure 2.6. Down-core POC concentrations and C/N values from Lake Salvador (station 1).

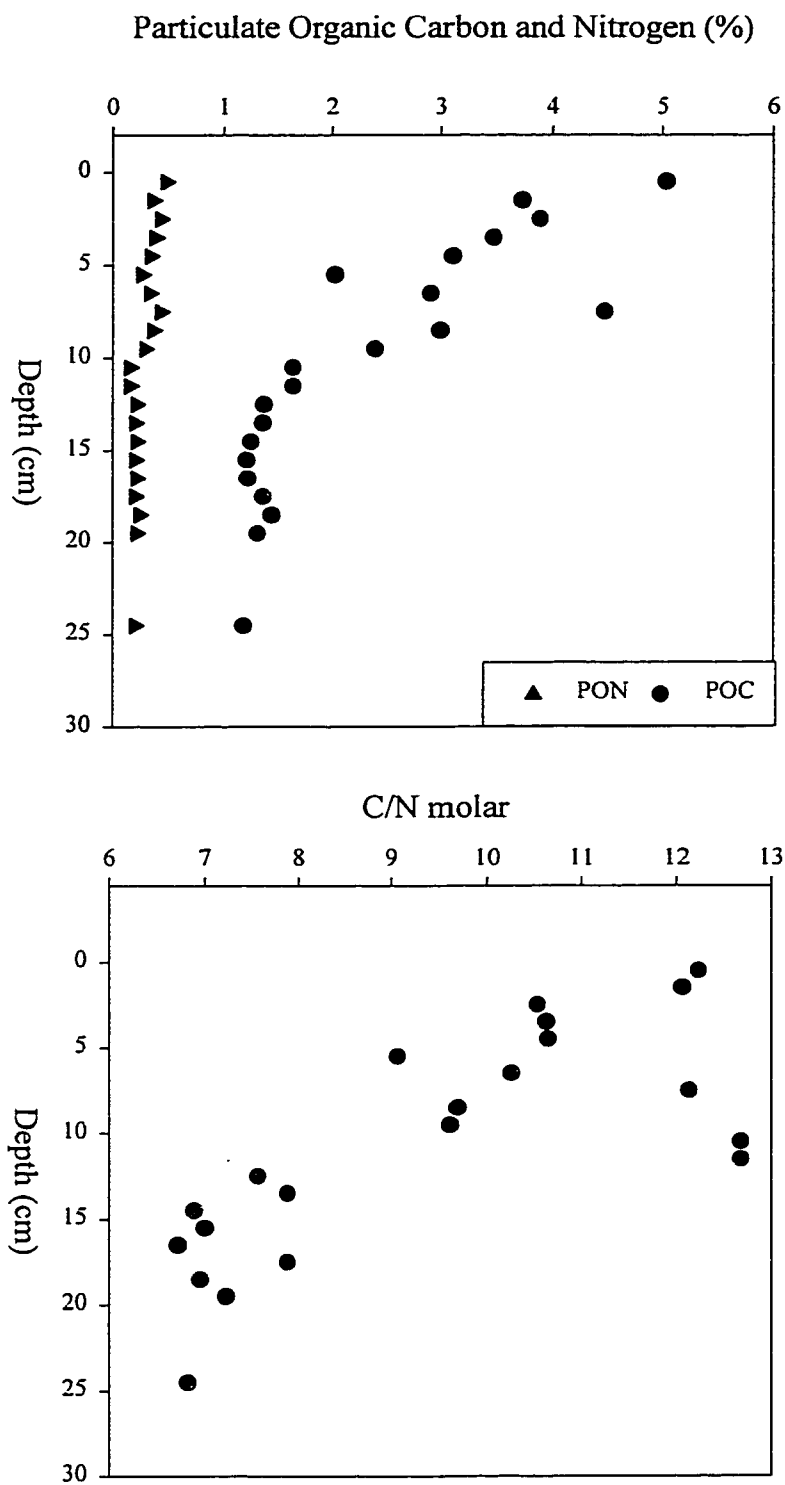


Figure 2.7. Down-core POC concentrations and C/N values from Lake Salvador (station 2).

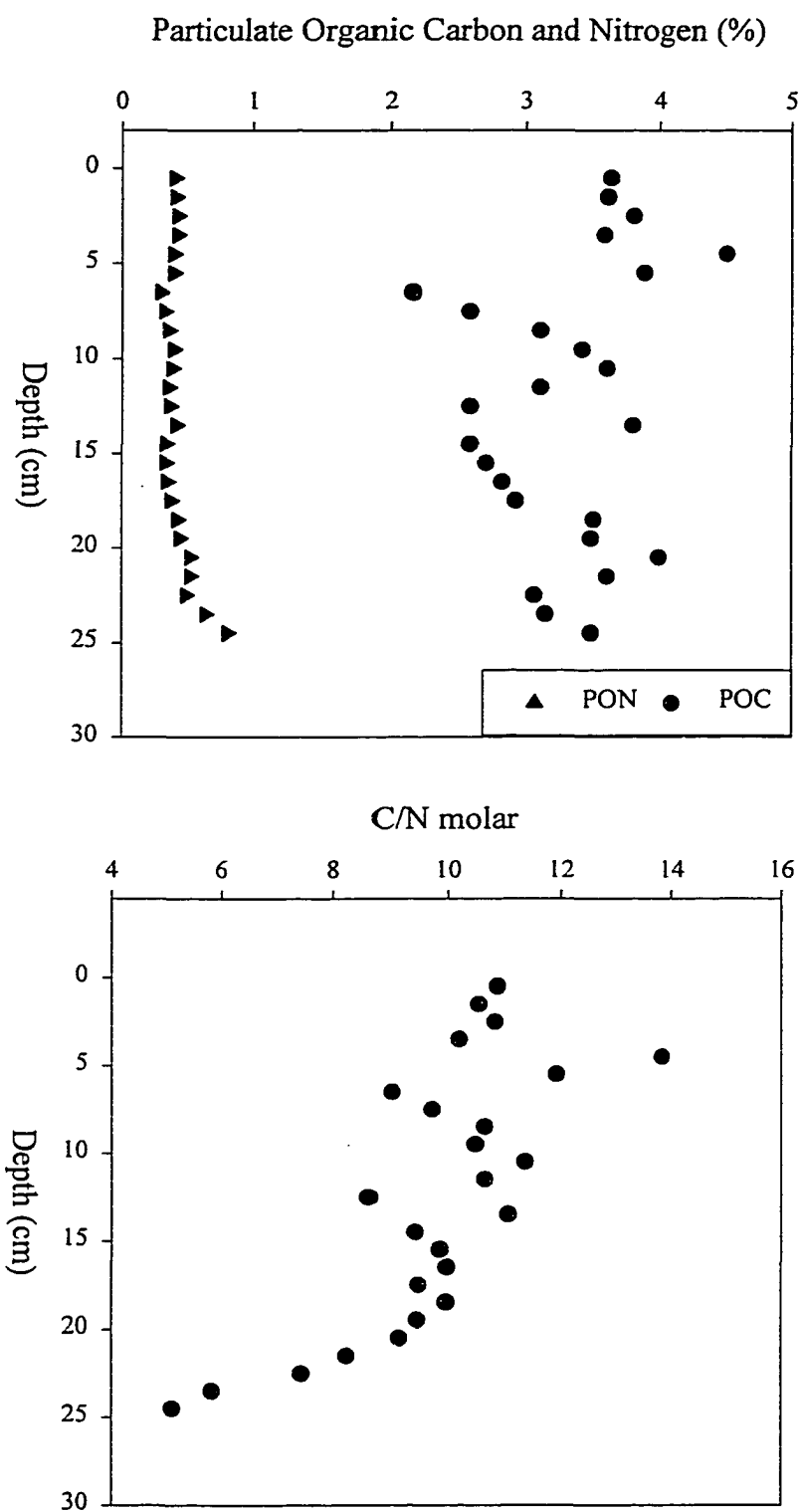


Figure 2.8. Down-core POC concentrations and C/N values from Lake Salvador (station 3).

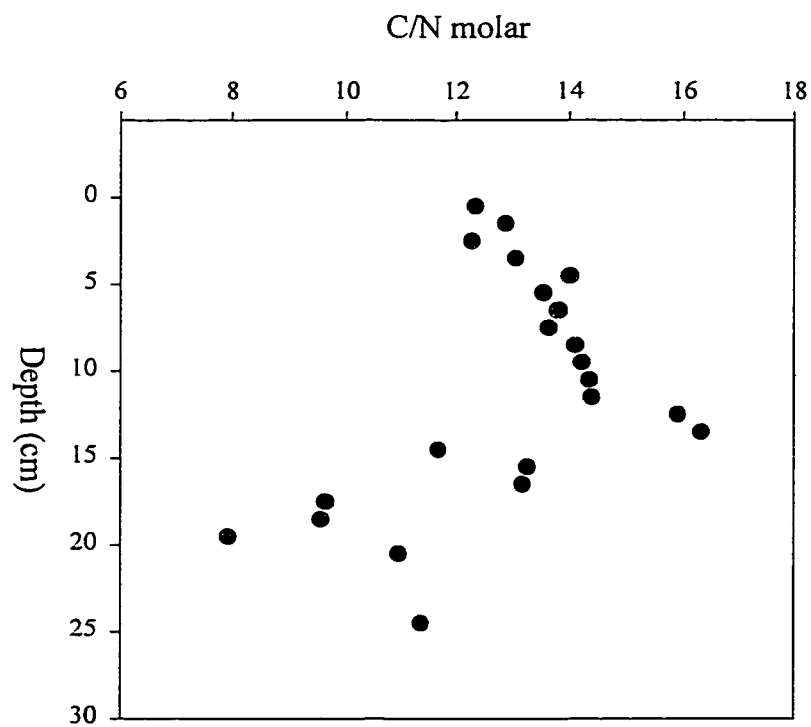
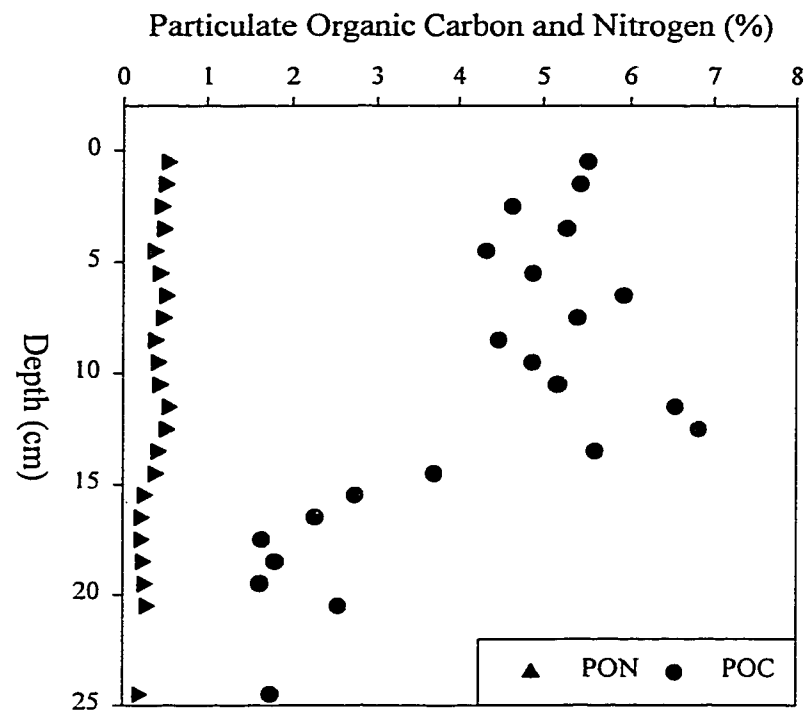


Figure 2.9. Down-core POC concentrations and C/N values from Little Lake.

exhibits only slight reductions in POC content and C/N values at depth, from 5 % to approximately 4 % with a C/N value of 13 (Fig.10). At the other extreme are cores collected from large open water bodies in the lower basin, such as Barataria Bay and Caminada Bay (Figure 3). These stations exhibit low POC contents (~ 1.5 %) and low C/N values (< 8) (Figs. 11 and 12). These sedimentary organic carbon characteristics are generally indicative of a marine carbon source (i.e. C/N values closely approximate the Redfield ratio). However, based on the low rate of sediment accumulation in the lower basin, which would not be conducive to burial of labile carbon, and the similarity of sedimentary organic carbon characteristics in the lower basin with samples at depth in Lake Salvador and Little Lake (i.e. low POC content and low C/N values), it seems more likely that this carbon derives from a highly degraded terrigenous source (i.e. marsh vegetation). A core collected in Bay Des Ilettes, which is located adjacent to and receives input from the Barataria Waterway, exhibits sedimentary organic carbon C/N values indicative of two distinct sources of allochthonous carbon (Fig. 13). The lower C/N values ranging from 7 to 10 resemble the characteristics at the Barataria and Caminada Bay stations, and likely result from frequent reworking (i.e. resuspension) enabling a more complete oxidative breakdown of the sedimentary carbon. The much higher C/N values, ranging from 14 to 16, dispersed intermittently throughout this core are indicative of less refractory terrigenous carbon that likely is derived from the Barataria Waterway, which receives inputs from the Inter-Coastal Waterway as well as water bodies in the middle basin.

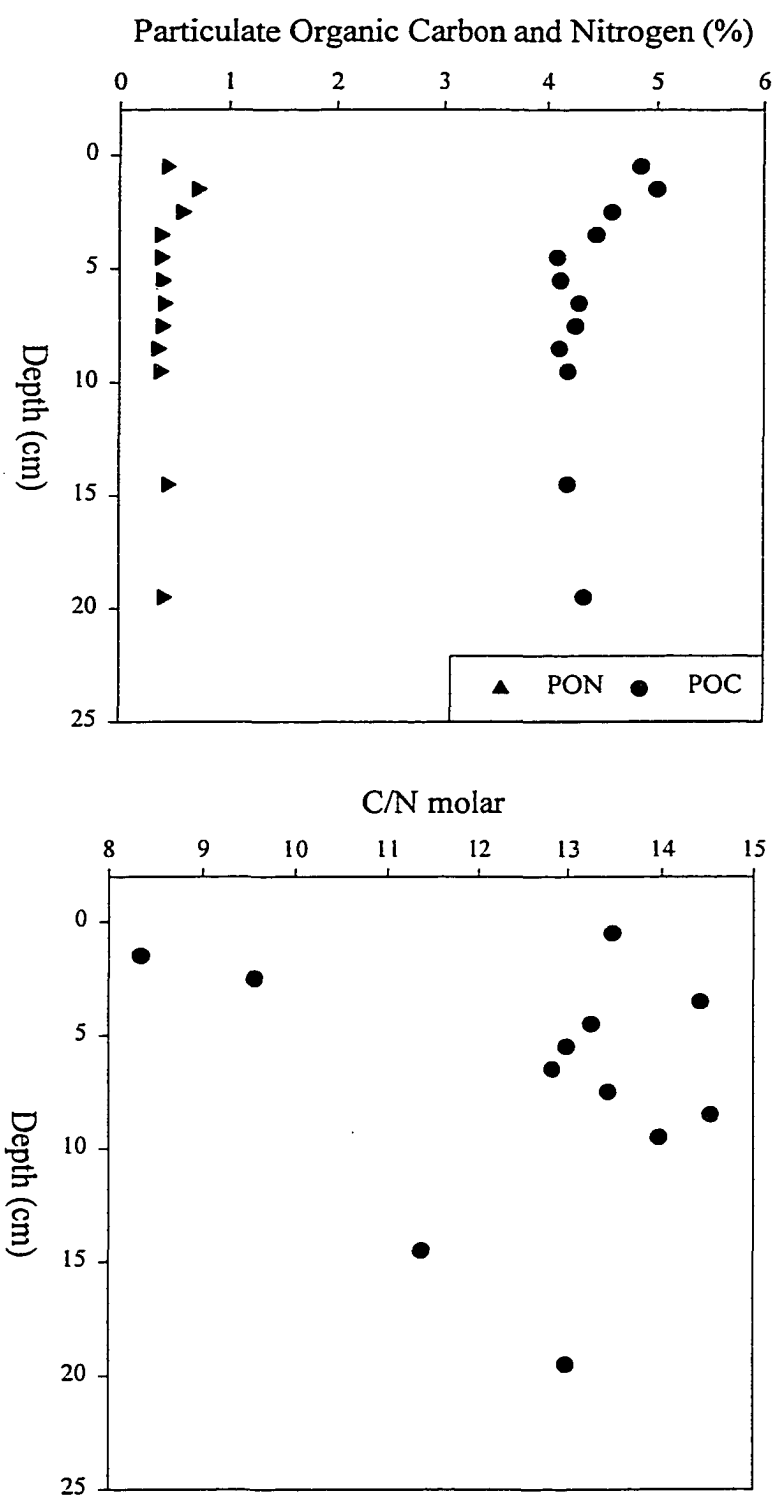


Figure 2.10. Down-core POC concentrations and C/N values from Live Oak Bay.

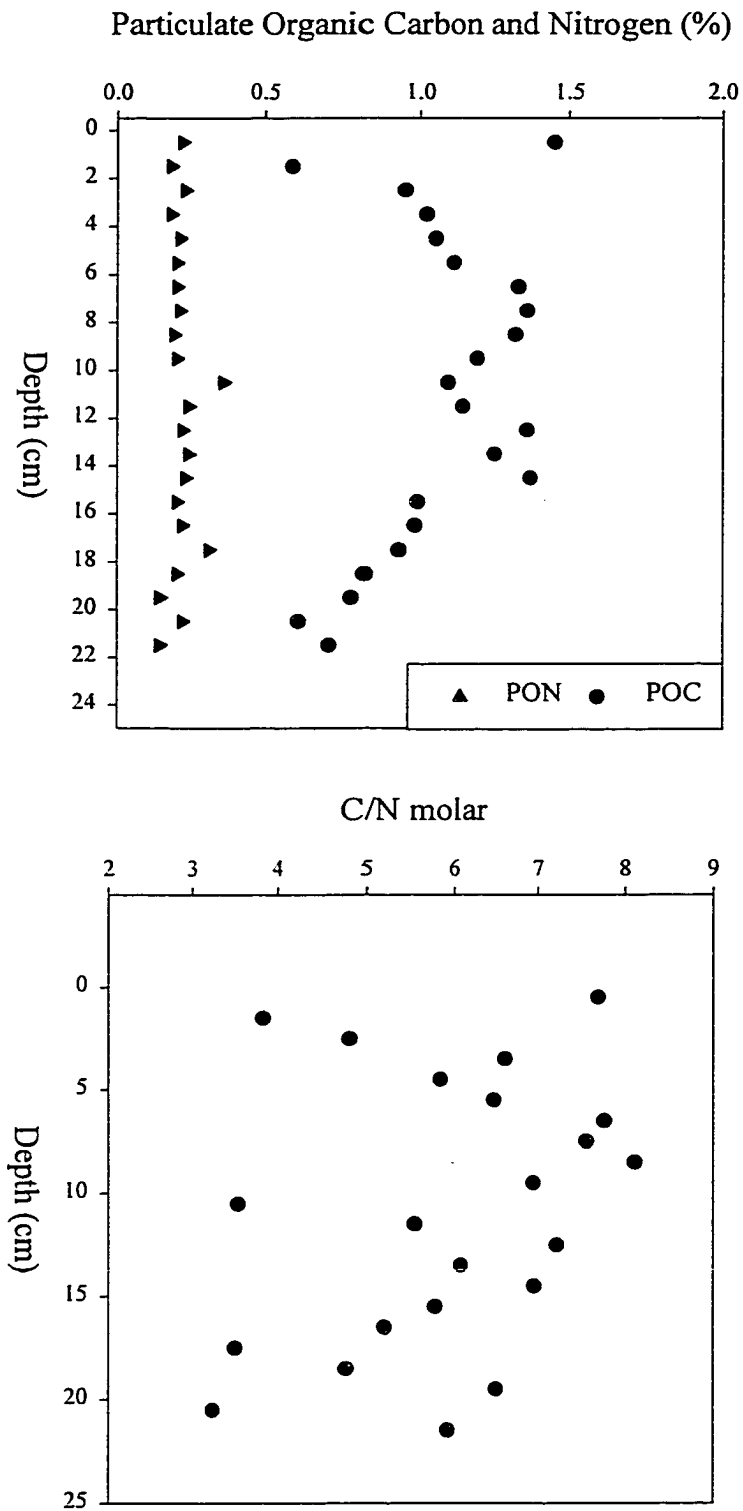


Figure 2.11. Down-core POC concentrations and C/N values from Barataria Bay.

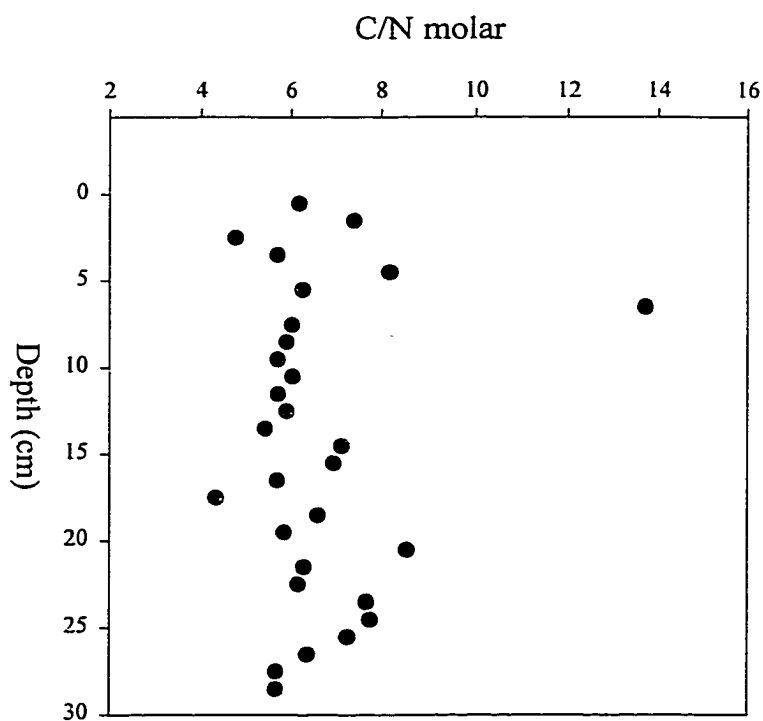
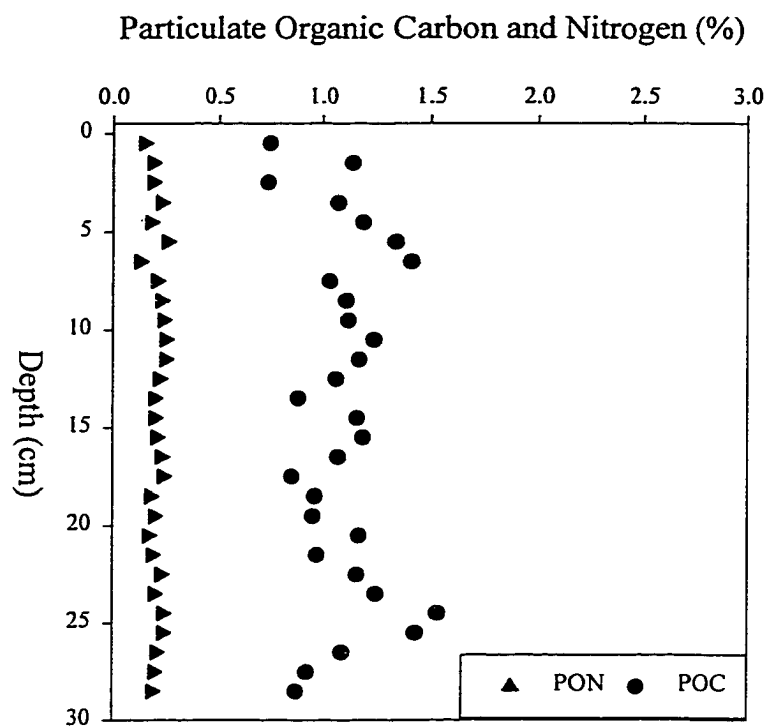


Figure 2.12. Down-core POC concentrations and C/N values from Caminada Bay.

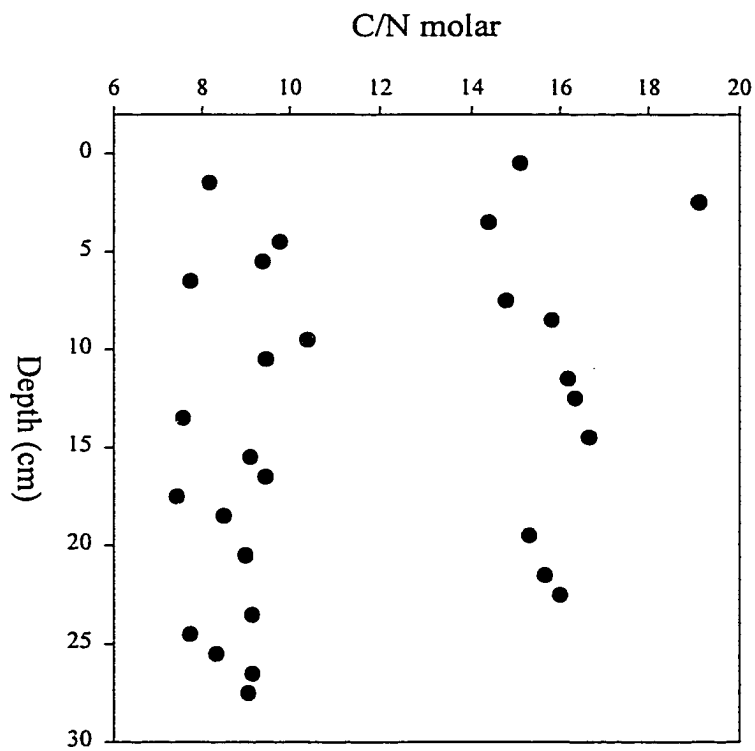
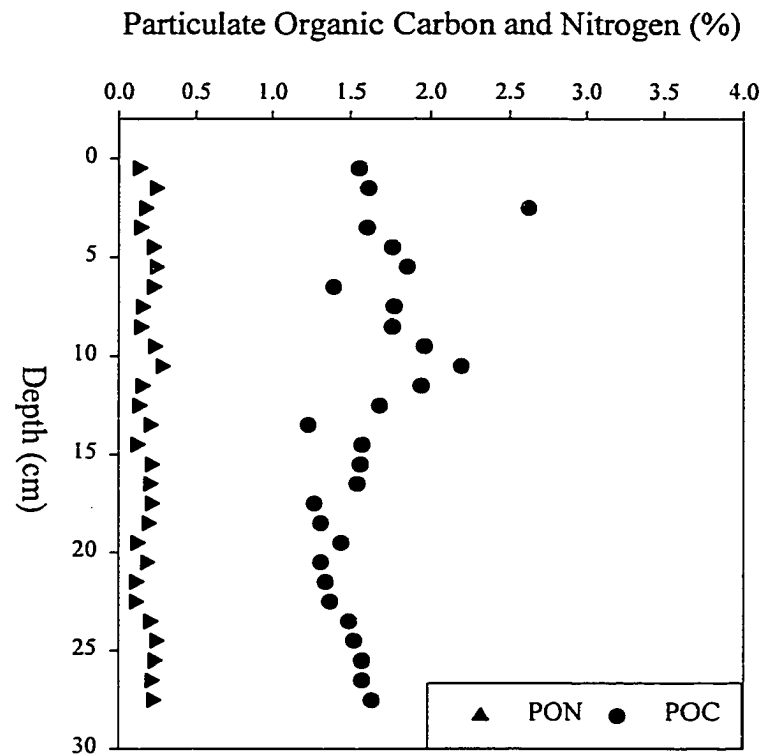


Figure 2.13. Down-core POC concentrations and C/N values from Bay Des Ilettes.

Previous stable carbon isotope work in the Barataria supports the highly weathered terrigenous source of sedimentary organic carbon in the lower basin proposed here. For example, Chmura et al., 1987 show that surface marsh sediments, from brackish and saline environments, exhibited depleted $\delta^{13}\text{C}$ values ($\sim 3\text{‰}$) to that expected from whole plant tissues, and attributed the difference to decomposition of plant tissues. In addition Delaune and Lindau, 1987, found that the $\delta^{13}\text{C}$ values in bottom sediments from brackish and saline environments also showed a negative shift in $\delta^{13}\text{C}$ from plant material, and found a linear relationship between increasingly negative $\delta^{13}\text{C}$ values and water body size. They attributed this relationship to the dominance of marine carbon in the larger water bodies as you move away from the marsh interface. However, an alternative interpretation would be that continued decomposition of the marsh material should result in increasingly negative $\delta^{13}\text{C}$ values (Chmura et al., 1987). Also, $\delta^{13}\text{C}$ values from C_3 marsh species appear to dominate the sedimentary organic carbon in Lake Salvador and Little Lake (i.e. $\delta^{13}\text{C}$ values range from -26.6 to -26.3) (Delaune and Lindau, 1987). During fall, winter and early spring strong northerly winds tend to resuspend sediments in Lake Salvador and Little Lake and transport them southward (Booth et al., 1999b). The mixing of C_3 carbon with the C_4 carbon produced in the lower basin would also result in a negative shift in $\delta^{13}\text{C}$ values for the lower basin.

SUMMARY

Data reported here indicate that POC is accumulating in bottom sediments at much higher rates in the short term (i.e. averaged over monthly time scales) ranging from 100 to 1000 g C m⁻² yr⁻¹ at two hydrologically contrasting stations, while POC burial rates (i.e. averaged over decadal time scales) from cores collected throughout the basin, range from 8 to 37 g C m⁻² yr⁻¹. The difference between deposition and burial, 73 to 960 g C m⁻² yr⁻¹ represents the amount of organic carbon available for export to the Gulf of Mexico or accumulation in marsh sediments. Wind energy distribution information indicates that during the cold front season, strong northerly winds will tend to transfer material to the adjacent Gulf of Mexico (Booth et al., 1999b). Additionally, the carbon that is transferred to the Gulf of Mexico may have marine carbon characteristics (i.e. low C/N values and $\delta^{13}\text{C}$ values of ~ 22 ‰) but actually be highly degraded terrestrial carbon (i.e. marsh detritus) from the deteriorating wetlands within the basin.

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CHAPTER 3

WIND INDUCED SEDIMENT RESUSPENSION IN A MICROTIDAL ESTUARY

INTRODUCTION

The global flux of river sediment to coastal margins is on the order of 15×10^9 t/yr and is largely ($> 80\%$) derived from tropical and subtropical rivers (i.e. between the latitudes of 30°N and 30°S) (Milliman and Meade, 1983; Milliman, 1991). The importance of these sediments in understanding element and pollutant transfer between the continents and oceans is well documented (Meybeck, 1982; Martin and Whitfield, 1983; Martin and Windom, 1991; Valette-Silver et. al., 1993). Coastal sedimentary deposits are a focal site for the biogeochemical transformation of many elements and their study is critical in understanding oceanic elemental mass balances and residence times (Holland, 1978; Berner, 1982; Martin and Windom, 1991). Therefore, knowledge of sediment dynamics in tropical and subtropical estuaries is important for understanding global biogeochemical budgets. However, much of our paradigm for how estuaries process materials is based on studies of temperate coastal environments (Nixon, 1981; Nixon and Pilson, 1983; Kemp and Boynton, 1984; Ward, 1985; Demers and Therriault, 1987; Sanford, 1994; Canuel and Martens, 1996). Fundamental differences exist between these estuarine environments (e.g. estuary type, mixing structure, water depth, tidal influence) that directly affect the way in which tropical and subtropical estuaries process material in comparison to temperate estuaries (Day et al., 1989; Alongi, 1998).

Physical processes (e.g. vertical mixing and sediment resuspension) influence important estuarine parameters such as: primary and secondary productivity, sediment mass flux, and pollutant dispersal. Storms have previously been recognized as important forcing mechanisms for sediment transport in coastal environments (Drake and Cacchione, 1985 and 1986; Cacchione et al., 1987; Roberts et al., 1988; Moeller et al., 1993). In shallow, micro-tidal coastal environments, wind induced waves can be the dominant physical forcing mechanism (Ward, 1980; Schroeder and Wiseman, 1999). Mathematical models describing wave formation and propagation have been developed by the U.S. Army Corps of Engineers (Coastal Engineering Research Center (CERC), 1977 and 1984). These models have been evaluated in coastal and lacustrine environments, and the results have been shown to give good agreement with field measurements (Carper and Bachmann, 1984; Schideler, 1984; Demers et al., 1987; Simon, 1989; Arfi et al., 1993).

The study of material transport in coastal environments requires the ability to analyze features which vary dramatically both in time and space. This variability limits the utility of *in situ* measurements for understanding the transfer and processing of materials in coastal margins. However, data obtained from satellites can provide the synoptic information required to study these complex environments (Gorden et al., 1983; Gagliardini et al., 1984; Voillier and Sturm, 1984; and Stumpf, 1988). In particular, data from the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) has been applied successfully in the study of coastal sediment dynamics (Stumpf,

1987; Stumpf and Pennock, 1989; Stumpf et al., 1993). The AVHRR is an effective tool for the study of many coastal environments because it provides daily global coverage, it has good radiometric resolution (i.e. ability to distinguish smaller differences in radiance), and it has the dynamic range (i.e., saturation radiance) to study even the most turbid waters (Stumpf, 1987; Gagliardini et al., 1984). The AVHRR instrument has a scanline (swath width) of 2048 pixels, a ground resolution of 1.1 km and is equipped with 5 spectral bands, 1 visible channel and 4 infrared channels.

Here we combine a wind driven resuspension model with remote sensing techniques to characterize sediment resuspension in the Barataria Basin, LA.

STUDY AREA

General Description

The Barataria Basin is an intertributary estuarine-wetland system located in southeast Louisiana (Fig. 1). It is bordered on the north and east by the Mississippi River and on the west by Bayou Lafourche. The basin has a total area of approximately 628,000 hectares (ha), including 202,000 ha of open water and 206,000 ha of marsh (Fig. 2; Conner and Day, 1987). Dominant morphological features include levees (natural and artificial), canals, bayous, bays, lakes, swamp and marsh wetlands, and barrier islands (Conner and Day, 1987). The Barataria estuary may be characterized as a bar-built lagoon; it is shallow with sandbars at the mouth and has a small tidal range (Adams et al., 1976). The average depth of open water bodies is approximately 2 meters (Conner and Day, 1987). Tides in the basin

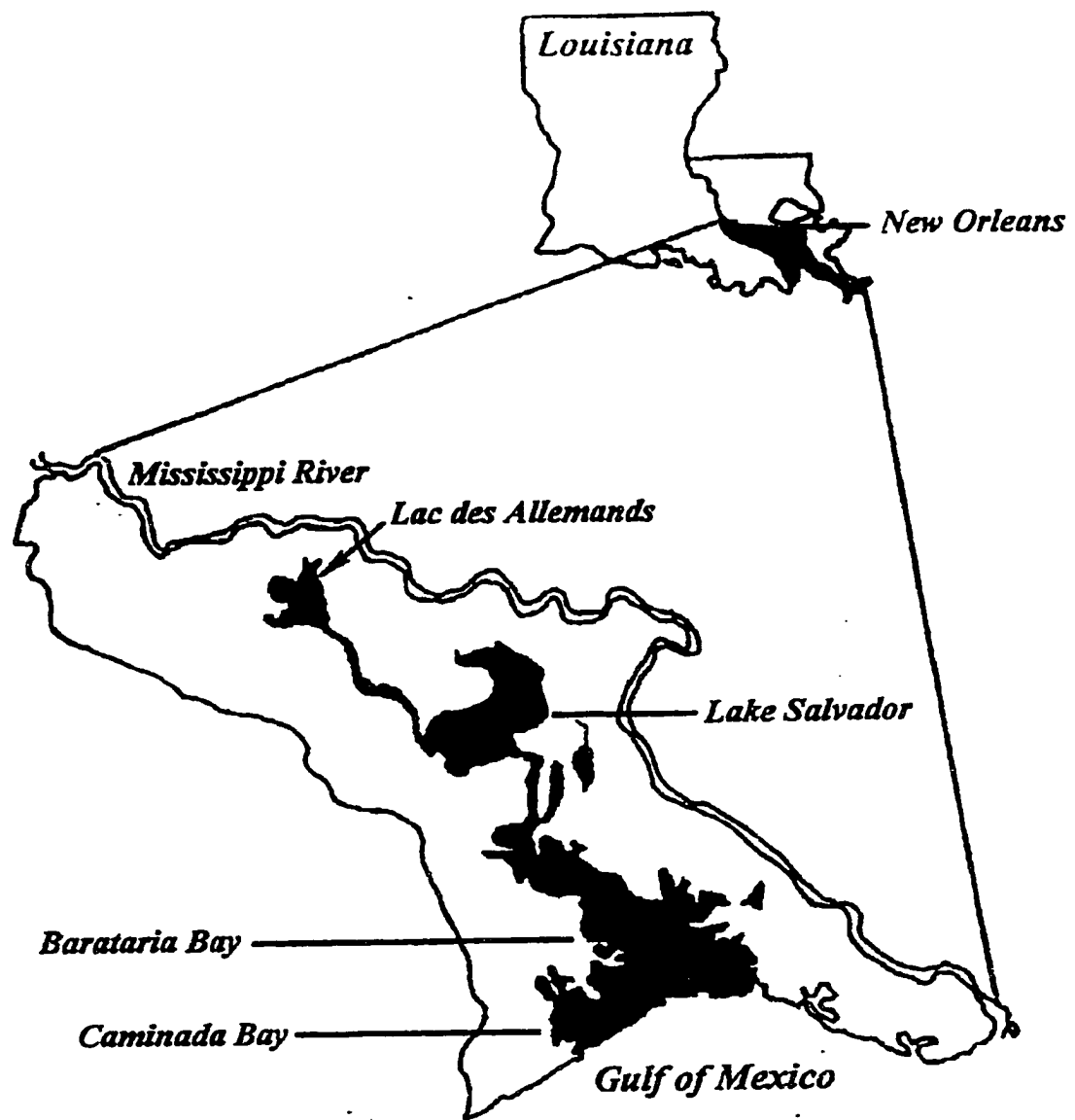


Figure 3.1. Location of the Barataria Basin with major water bodies identified.

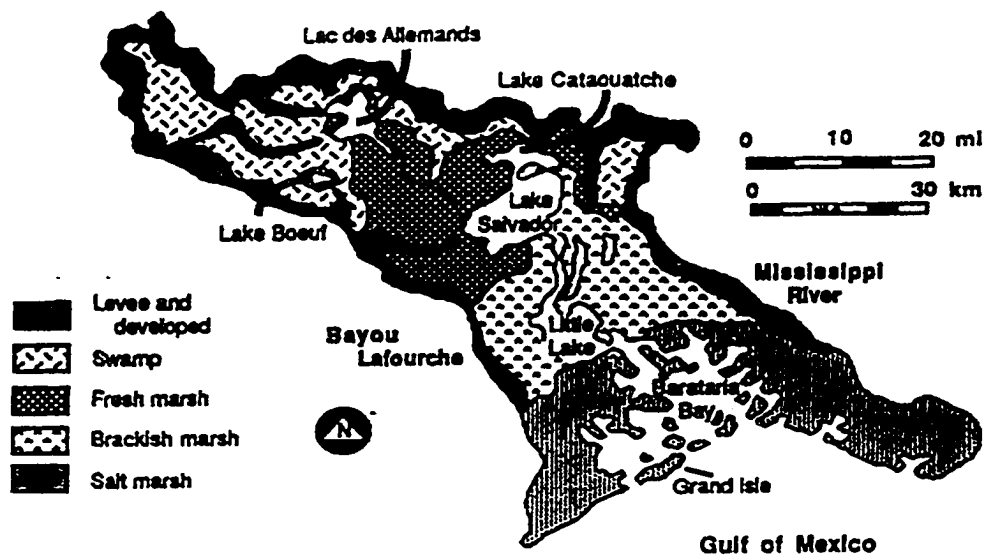


Figure 3.2. Habitat map of the Barataria Basin (from Conner and Day, 1987).

are diurnal with an average range of 32 cm at the coast (Baumann, 1987). On average, coastal Louisiana receives about 160 cm of precipitation annually (Baumann, 1987). Presently, the basin is experiencing reduced freshwater input (due to leveeing of the Mississippi River and surrounding waterways), increasing salinity and wetland erosion, resulting in a rapid transition back to an open marine environment (Madden et al., 1989).

Climate

The climate of the Barataria is largely controlled by its subtropical location and proximity to the Gulf of Mexico (Sanders, 1978). Seasonal weather patterns for coastal Louisiana are primarily influenced by two pressure systems; the Bermuda High and the Mexican Heat Low (Leipper, 1954; Baumann, 1987). The Bermuda High is located over the Bermuda-Azores area of the western Atlantic and is weakened and in a northerly location during the winter, and strengthened and in a southerly location during spring and summer (Schroeder and Wiseman, 1999). The Mexican Heat Low is located over Texas and is well established during the summer (Baumann, 1987). The position and relative strength of the Bermuda High imparts a steering effect on high pressure systems advancing southward over the conterminous U.S., and ultimately determines the orientation and southern extent of a front as it crosses coastal Louisiana. The Mexican Heat Low influences the speed and direction of southerly dominant winds, during the summer months, due to its position and strength. Therefore, during winter northerly winds are dominant with northeasterly winds occurring most frequently whereas, during the summer southerly

winds become dominant with southeasterly winds occurring most frequently (Baumann, 1987).

Hydrology

The Barataria Basin is a meteorologically forced, micro-tidal estuary (Boesch et al., 1989). Water movement through the basin is a function of tidal influence, winds and precipitation. The combination of these influences creates slow moving bayous and promotes sheet flow over the wetlands (Conner and Day, 1987). Seasonal water level in the basin exhibits a bimodal distribution with maximum water levels occurring in the spring, due to precipitation and runoff, and summer, due to an expanding Gulf water mass (Baumann, 1987). The spring peak is discernable but considerably attenuated for locations in the lower basin. This is attributed to a decreased upland runoff influence (marine dominance) for the lower basin (Baumann, 1987).

The natural hydrology of the basin has been altered extensively by human activities such as, channel dredging and levee construction (Turner and Cahoon, 1988). For example, leveeing of the Mississippi River has effectively eliminated the major fluvial input of freshwater and sediments to the basin. Precipitation is now the primary source of freshwater. Linear canals dredged to depths greater than the surrounding bay bottoms promote the intrusion of high salinity water into the interior basin, and also provide efficient conduits for the transport of materials out of the basin. The overall effect of these activities has been to decrease the transfer of

sediments to the marsh surface, thereby decreasing the sustainable marsh area of the basin.

Material Transport

The transfer of material (e.g. silt, clay, organic matter and nutrients) within the basin depends on water movement. Before the river was leveed, the bulk of material transport occurred in the spring in relation to the annual Mississippi River flood. Presently, maximum water exchange in the Barataria occurs in the fall and winter in response to the passage of cold fronts (Baumann, 1987; Madden et al., 1988). During these seasons an average of over 5 frontal passages occur per month (Baumann, 1987). As a cold front approaches the coast, southerly component winds strengthen and push water into the basin, flooding the marshes. After the front passes, northerly component winds become dominant and push the water out of the basin, draining the marshes. Water level variability in the marsh approaching 1 m d^{-1} has been documented in relation to wind stress (Muller, 1979). This scenario is repeated for each frontal passage and has been shown to be important for material transport in the basin. Storm passages are now the only mechanism that transports sediments to the surface of the marsh. A study of the seasonality of marsh accretion indicates that as much as 75% of the annual accretion results from winter storm passages, in years when tropical storms did not impact the basin (Baumann et al., 1984). The source of these sediments is primarily resuspended bottom sediments from lakes and bays (Madden et al., 1988).

THEORY

Predicting Resuspension from Wind-Induced Waves

Surface waves are produced when wind blows across a body of water. A wave traveling in water with a depth (d) that is greater than one-half the wavelength (L) is classified as a deepwater wave (Pond and Pickard, 1983; Fig. 3). As a deepwater wave propagates, surface water particles move in an approximately circular path (Fig 3). The radius of this path decreases exponentially with depth, approaching zero at $L/2$ (Pond and Pickard, 1983). When $d < 1/2L$, the wave motion reaches the bottom and the wave transfers energy to the bottom sediments, possibly causing resuspension. Therefore, wavelength (L) is the critical parameter for characterizing resuspension for a given water body. Wavelength is related to wave period by

$$L = gT^2/2\pi, \quad (1)$$

where g is gravitational acceleration (9.8 m s^{-2}) and T is the wave period (CERC, 1984). The period of wind induced waves is determined primarily by wind velocity, wind fetch and wind duration. If 24 hour resultant wind vectors are used, then T can be predicted from the wind velocity (U) and fetch (F) given that (CERC, 1984)

$$gT_m/U_A = 0.2857(gF/U_A^2)^{1/3}, \quad (2)$$

where U_A is a wind stress factor and is determined from

$$U_A = 0.71(UR_T)^{1.23}. \quad (3)$$

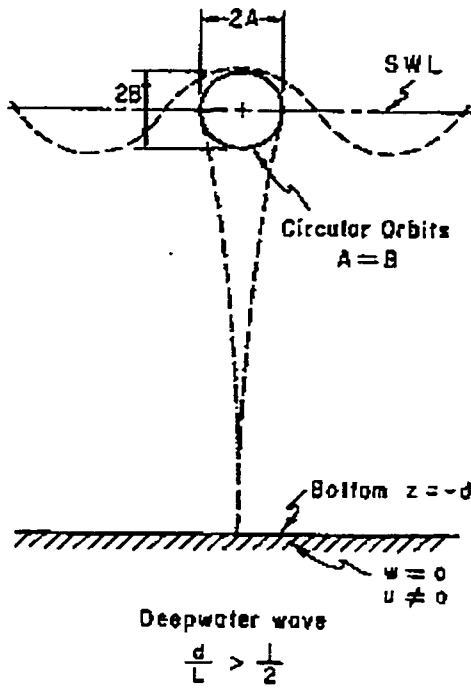


Figure 3.3. Water particle motion for deepwater waves (from the U.S. Army Coastal Engineering Research Center, 1977).

R_T is a boundary layer stability correction factor, which is dependent on the temperature difference between the water and air and is expressed as

$$R_T = f(T_a - T_s), \quad (4)$$

where T_a and T_s represent the temperature of the air and surface water. When temperature information is not available a value of 1.1 should be used for R_T (CERC, 1984).

Remote Sensing of Suspended Sediments

The optical properties of water, in the visual portion (400 – 700 nm) of the electromagnetic spectrum, result from the concentrations of suspended and dissolved constituents in the water column. A quantitative application of remote sensing to the study of ocean optics requires an understanding of how the total spectral signal measured at a remote instrument can be partitioned into water-leaving and non water-leaving components. The total radiance (L_t) measured at the sensor can be written as

$$L_t(\lambda) = L_A(\lambda) + tL_w(\lambda) + L_{sg}(\lambda), \quad (5)$$

where t is the diffuse transmittance of the light through the atmosphere, λ is the sensor band or wavelength, L_w is the water-leaving radiance, L_A is the radiance attributed to atmospheric scattering, and L_{sg} is the radiance attributed to sunglint from surface water. It is the water-leaving component that contains information on the water constituents, while the non water-leaving component is related to viewing the water through the atmosphere.

By avoiding regions of an image that contain sunglint, L_{sg} can be omitted from equation 5. The atmospheric path radiance (L_A) is estimated by applying the clear water subtraction technique (Gordon et. al., 1978). This technique utilizes the fact that clear water is a strong absorber of long wavelength energy (e.g. red and near-IR regions) and in the absence of suspended particulates, $L_w = 0$. Therefore, the radiance values measured in these regions of the electromagnetic spectrum are due to atmospheric scattering. The concentration and size distribution of aerosol particles is assumed constant over the entire scene and the clear water radiance representative of the atmospheric component at all wavelengths (Stumpf, 1987). The water-leaving radiance can be extracted from the total radiance ($L_t(\lambda)$) by rearranging equation 5,

$$L_w(\lambda) = \{L_t(\lambda) - (L_A(\lambda))\} / t(\lambda). \quad (6)$$

However, L_w is not an accurate indicator of water properties as it is influenced as much by the incident solar irradiance as the water quality (Robinson, 1985). By normalizing the radiance measured at the satellite for the incident light field at the ocean surface (E_d), we obtain remote sensing reflectance

$$R_{RS}(\lambda) = L_w(\lambda)/E_d(\lambda), \quad (7)$$

which is directly related to water turbidity (Stumpf, 1987). E_d is calculated by propagating the solar irradiance at the top of the atmosphere (E_o) to the ocean surface by correcting for the sun's altitude and the Earth – Sun distance, and is given by $E_d = E_o \cos \theta_o$, where $E_o = \underline{E}_o [1 + 0.0167 \cos [2\pi(D-3)]]^2$, D is the Julian day of data collection, \underline{E}_o is the mean solar constant and θ_o is the solar zenith angle (Stumpf, 1987). Therefore,

$$R_{RS}(\lambda) = L_w(\lambda)/E_o(\lambda) \cos(\theta_o) T_l, \quad (8)$$

where atmospheric attenuation of E_o (from the sun to the earth) is represented by T_l .

METHODS

Seasonal Turbidity via Remote Sensing

AVHRR level 1b Local Area Coverage (LAC) and High Resolution Picture Transmission (HRPT) imagery was obtained from the NOAA Satellite Active Archive (<http://sit.saa.noaa.gov/>). Channel 1 and 2 data for images that contained little or no cloud cover in the study region were processed and analyzed using the *ENVI* (Research Systems, Inc., Boulder, CO) software package. The radiances were georeferenced and converted to percent reflectance using a one-step algorithm (Di and Rundquist, 1994). This algorithm applies the auxiliary parameters (e.g. calibration coefficients, Earth location, solar-zenith angles) appended to level 1b data to remove geometric and radiometric errors. The calibrated reflectances were used to calculate the remote sensing reflectance of Eq. (8). The atmospheric transmissions t and T_l were taken to be unity, which leads to R_{RS} values that are underestimates of the true reflectance. In this study we are interested only in the relative differences in reflectance values among the pixels in a particular scene, and therefore, the actual values of t and T_l are not important. The clear water reflectance was subtracted from the total reflectance R_t of each pixel in the scene. The resulting quantity is

$$R_{RS} = (R_t - R_{lc})/E_o \cos \theta_o, \quad (9)$$

where R_{lc} represents the total reflectance measured over clear water.

Wind Characteristics

Hourly wind data (direction and speed) were obtained from the NOAA National Data Buoy Center (NDBC) (<http://seaboard.ndbc.noaa.gov/>) meteorological buoy located just south of Grand Isle, Louisiana (buoy ID = GDIL1). The data were normalized to wind speeds 10 meters above the sea surface using

$$U(10m) = U(z) (10/z)^{1/7}, \quad (10)$$

where U represents wind speed in m/s and z represents the height above sea surface that the winds were measured (CERC, 1984). This equation is valid for winds measured over water when $z \leq 20$ meters (CERC, 1984). The normalized wind data were used to characterize seasonal winds and to drive the resuspension model. Wind data were divided into 10 periods covering the time frame from Sept. 23, 1995 to Jan. 4, 1997. These periods were further grouped into seasons: fall and winter encompassed September through February; spring included March through May; while summer included the months of June through August.

Modeling Wind-Induced Resuspension

A computer program was written to calculate fetch (F), critical wind speed (U_c), wavelength (L) and wave period (T) across a body of water, for winds of any speed blowing from the eight primary compass directions as defined in Figure 4. Navigation charts were digitized to provide shoreline boundaries and bathymetry for the program. A file of each of the model parameters was generated for each program run. These files were imported into ENVI for processing and visualization. The following parameters were calculated from equations 1 and 2 above:

$$\begin{aligned}
T_c \text{ (critical wave period)} &= (4\pi d/g)^{1/2} \\
U_c \text{ (critical wind speed)} &= [1.2\{4127(T_c^3/F)\}^{0.813}] \\
T \text{ (significant wave period)} &= [0.2857(gF)^{1/3} U_A^{1/3}]/g \\
L \text{ (wavelength)} &= gT^2/2\pi \\
RP \text{ (resuspension potential)} &= U - U_c
\end{aligned}$$

Resuspension Model Validation

Because no *in situ* turbidity measurements were available to check the validity of the resuspension model, we compared reflectance values from the satellite imagery to model predictions of resuspension potential. Thus, an image of U_c for a water body, corresponding to the wind characteristics from a given day, was compared to the AVHRR image collected on the same day. Specifically, the 24 hour resultant wind vector was calculated for a given day that a useable (i.e. cloud free) AVHRR image was available. This wind data was used for the model run. The model output image for U_c was resampled to 1km resolution to permit a direct comparison with the satellite imagery. Corresponding transects were then subsampled to obtain U_c and reflectance data. The U_c data were then subtracted from the mean wind speed (U) for that day to produce the RP parameter. The model was validated using data from Lake Pontchartrain because advective inputs to the lake were minimal compared to water bodies within the Barataria Basin (advective inputs will tend to skew the reflectance data either higher or lower depending on the source of the advected waters). Lake Pontchartrain is a large (1645 km²), shallow (average depth is 4 m) water body located on the northern boundary of the study area

and is hydrologically isolated (i.e. the majority of suspended material in the water column is generated from within the lake) in comparison to the open water bodies within the Barataria Basin.

RESULTS AND DISCUSSION

Seasonal Wind Forcing

Wind data exhibited expected trends, with the strongest winds occurring in the fall, winter and early spring in conjunction with cold front passages. Mean daily wind speeds ranged from 5.7 m/s in the fall to 2.8 m/s in the summer (Figure 5). Northerly component winds (i.e. winds from the NW, N and NE) were always stronger than southerly component winds (i.e. winds from the SW, S and SE), with the exception of late spring and summer (Figure 5). During fall and winter northerly component winds were dominant and averaged 6.5 m/s, while southerly component winds averaged 3.6 m/s (Figure 5). However, during summer months southerly component winds became dominant and averaged 2.9 m/s, while northerly component winds averaged 1.8 m/s (Figure 5).

The directional distribution of wind energy (U^2) for this study (Table 1) reveals that northerly component winds were the primary forcing agent, accounting for 58% of the total wind energy; while southerly component winds contributed 26% of the wind energy. A seven-year average for directional wind energy distribution (Table 2) returned values of 52% and 26% for northerly and southerly component winds. Therefore, it appears that for a typical year the net transfer direction for

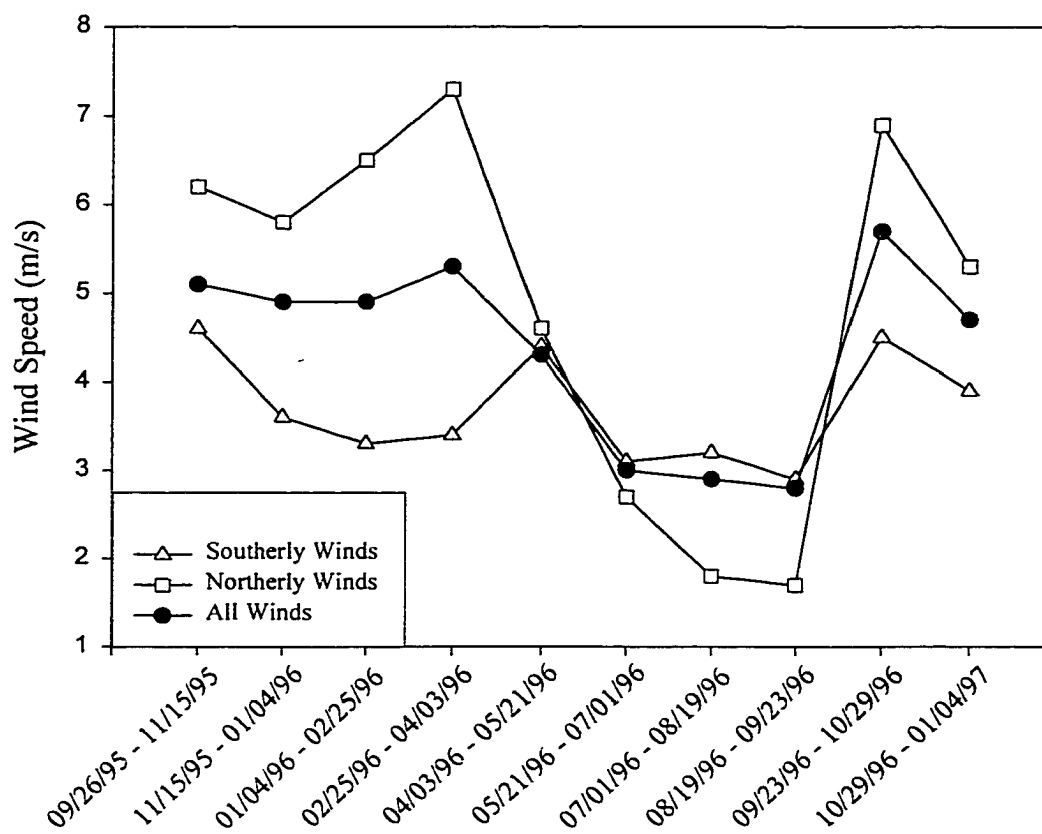


Figure 3.5. Mean daily wind speeds for each time period. Northerly and southerly winds include westerly and easterly components (i.e. N, NW, NE and S, SW, SE).

Table 3.1. Directional wind energy distribution for each period of this study. Winds were sorted according to Figure 5. Bold numbers at the bottom represent directional totals and percent of total wind energy for this study.

Period	NW	N	NE	E	SE	S	SW	W	Σ energy (m^2s^{-2})
1	6.1	32.3	37.5	10.5	6.9	2.2	2.1	2.4	54358
2	8.8	38.8	17.6	8.3	5.4	5.8	3.1	12.2	40488
3	27.7	29.2	9.1	8.1	9.3	6.0	6.2	4.3	44884
4	15.6	35.4	16.0	5.7	9.0	4.2	3.1	11.0	38882
5	9.0	16.3	8.6	8.3	44.0	10.4	2.0	1.3	31582
6	7.2	5.4	5.9	11.1	21.1	29.5	10.2	9.7	14365
7	10.8	4.3	4.1	10.7	17.5	16.1	16.8	19.7	19159
8	7.0	5.6	10.5	30.8	7.5	11.8	18.9	7.8	13759
9	5.6	23.5	49.9	8.7	7.5	4.0	0.1	0.8	37022
10	15.5	19.6	17.5	15.5	8.2	9.2	4.7	9.7	48219
Total	41833.4	85806.3	70521.8	36118.4	41653.1	26017.7	16604.1	24076.1	342718.0
%	12.2	25.0	20.6	10.5	12.2	7.6	4.8	7.0	100

water-borne materials (i.e. dissolved and particulate materials) should be southerly. Ultimately, what controls the affect of these northerlies on the basin, for a given year, are the characteristics of cold front passages (i.e. orientation to the coastal environment, strength, speed and direction of propagation). However, in years when a tropical storm or hurricane impacts the basin, the directional wind energy distribution could be significantly influenced (i.e. depending on the path of the system).

Resuspension Model Results

For a given scenario of wind speed, direction and fetch over water, as the resuspension potential increases above the value of zero, a concomitant increase in water column turbidity, here measured as reflectance, should result. Model estimates of resuspension potential (RP) show good agreement with satellite reflectance data (Figure 6) for Lake Pontchartrain. The covariance between RP and % reflectance indicates that the model prediction of when resuspension should occur is reasonable. Model estimates of U_c for Lake Salvador, Little Lake and the lower Barataria Basin were calculated for each of the eight wind directions indicated in Figure 5. Contour plots of U_c for due north and south winds for each water body are depicted in (Figures 7 - 9). Because of the shallow nature of these water bodies, areas of resuspension are primarily determined by the fetch. Therefore, critical windspeeds are high near the windward shores of the water bodies and low near the leeward shores. Areal estimates of bottom sediment resuspension are given as a function of

Table 3.2. Directional wind energy distribution for 1990 through 1996. Winds were sorted according to Figure 5. Bold numbers at the bottom represent directional totals and percent of total wind energy during the seven-year period.

Year	NW	N	NE	E	SE	S	SW	W	Σ energy (m^2s^{-2})
1990	12.0	22.8	14.8	18.6	15.9	6.8	3.8	5.2	253181.1
1991	8.6	15.1	21.4	20.5	16.3	8.7	4.4	5.1	296282.4
1992	10.0	18.2	24.7	14.9	12.0	6.8	6.4	6.8	269045.5
1993	14.0	20.1	18.9	16.7	10.6	6.7	4.6	8.3	285808.7
1994	11.6	20.8	22.5	15.8	10.5	7.7	6.0	5.2	274577.6
1995	10.2	24.0	20.7	12.9	11.6	9.1	4.8	6.8	315524.1
1996	15.1	20.1	17.1	10.8	14.3	9.0	5.8	7.9	297216.9
Totals*	231694	401456	399265	311833	259065	157042	101882	129507	1991636.2
%	11.6	20.2	20.0	15.7	13.0	7.9	5.1	6.5	100.0

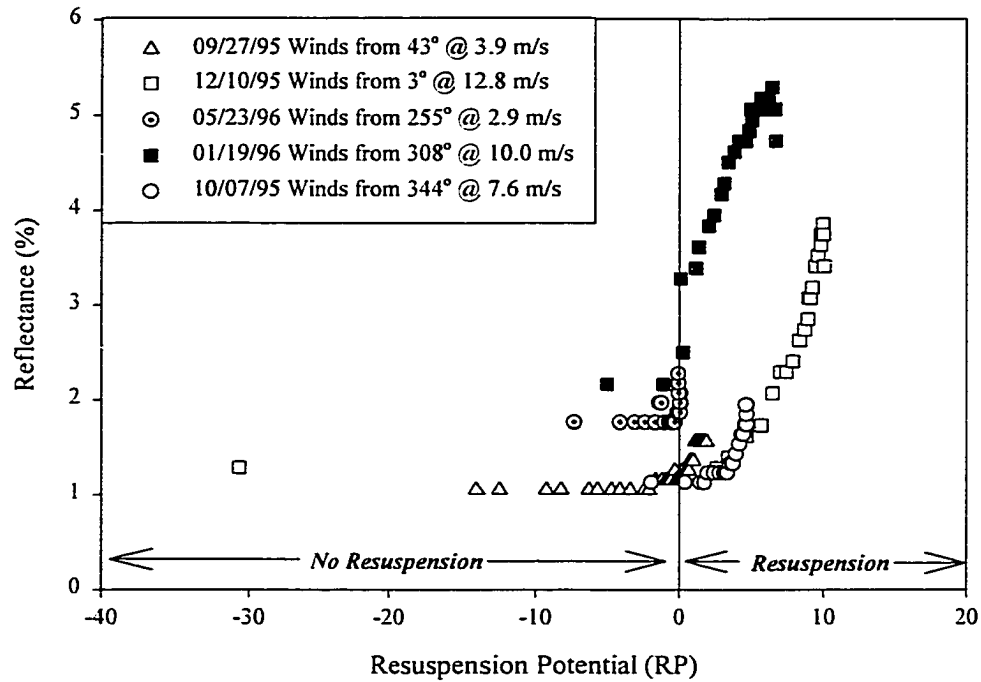


Figure 3.6. Model prediction of resuspension potential (RP) vs. AVHRR channel 1 reflectance. Reflectance (or water turbidity) exhibits good agreement with model estimates of when resuspension should occur (i.e. RP values of 0 and above).

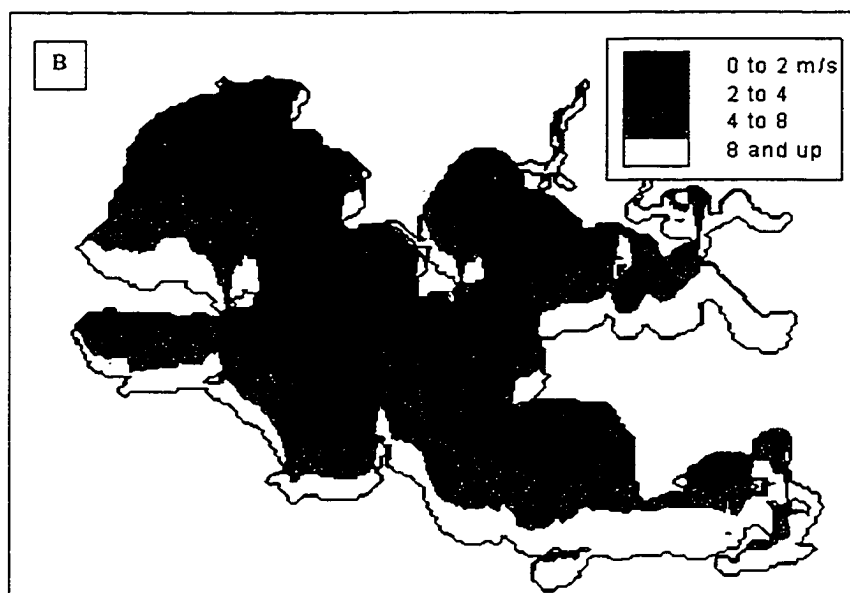
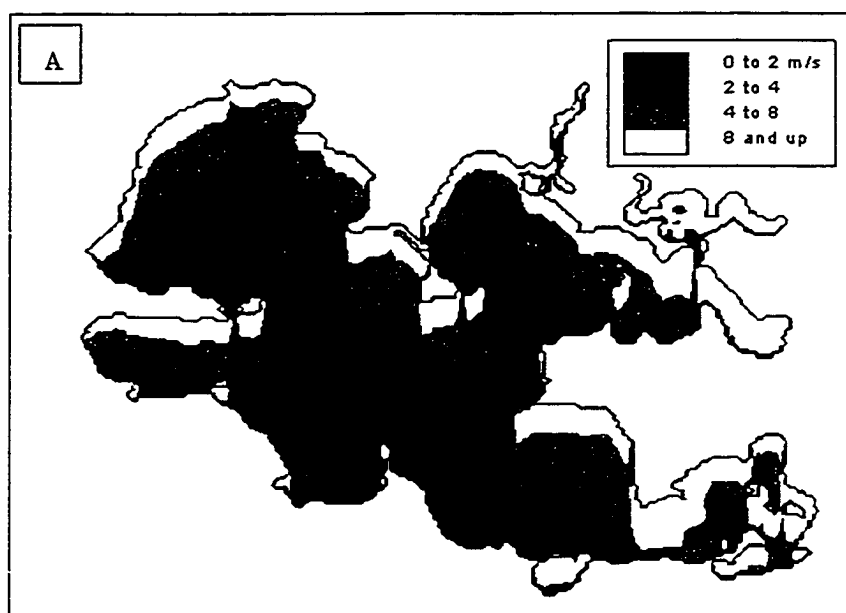


Figure 3.7. Isopleths of U_c (m/s) in Little Lake. Isolines represent the windspeed required to induce resuspension for a north wind (360°) (A) and south wind (180°) (B). Each contour represents the region that would be subject to resuspension at the indicated wind speed.

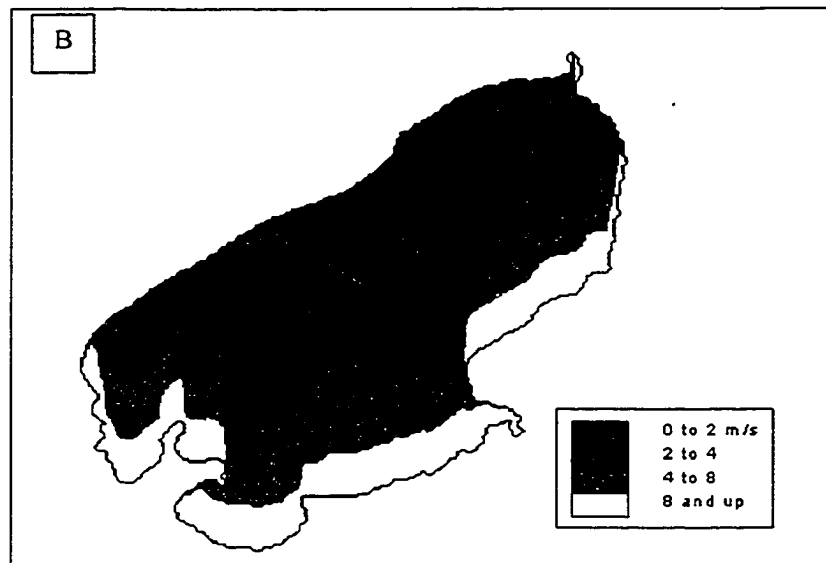
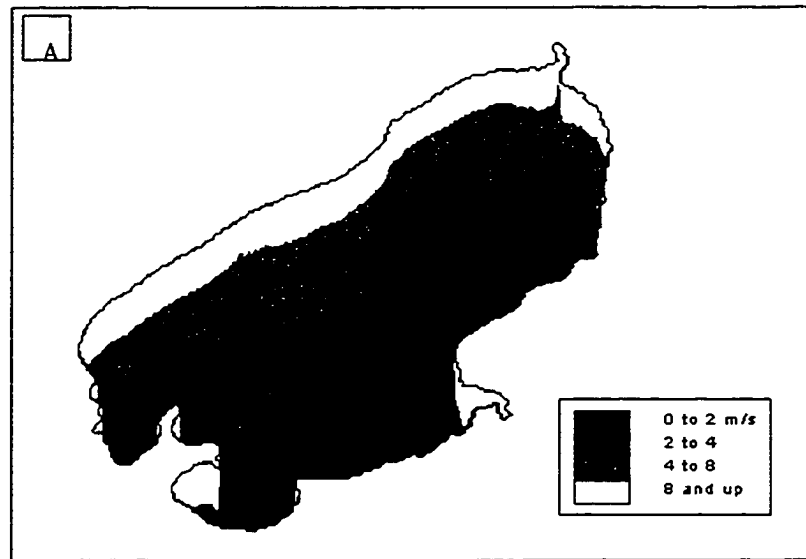


Figure 3.8. Isopleths of U_c (m/s) in Lake Salvador. Isolines represent the windspeed required to induce resuspension for a north wind (360°) (A) and a south wind (180°) (B). Each contour represents the region that would be subject to resuspension at the indicated windspeed.

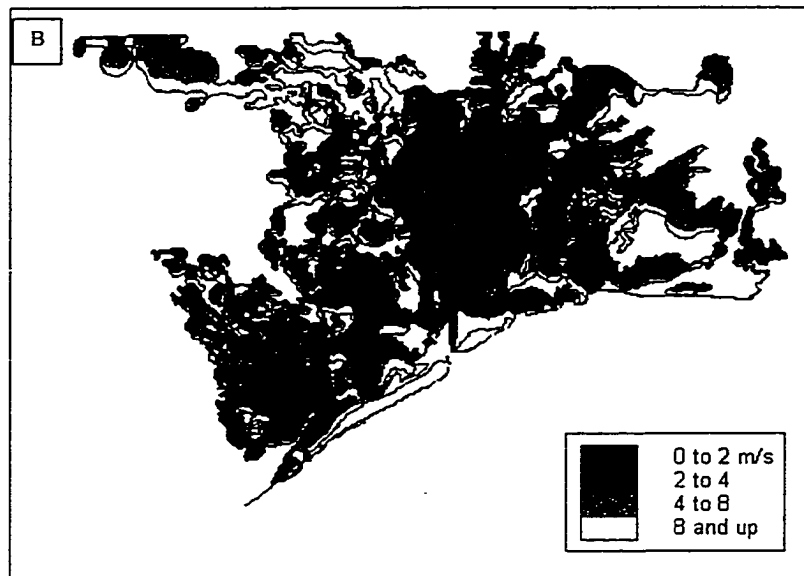
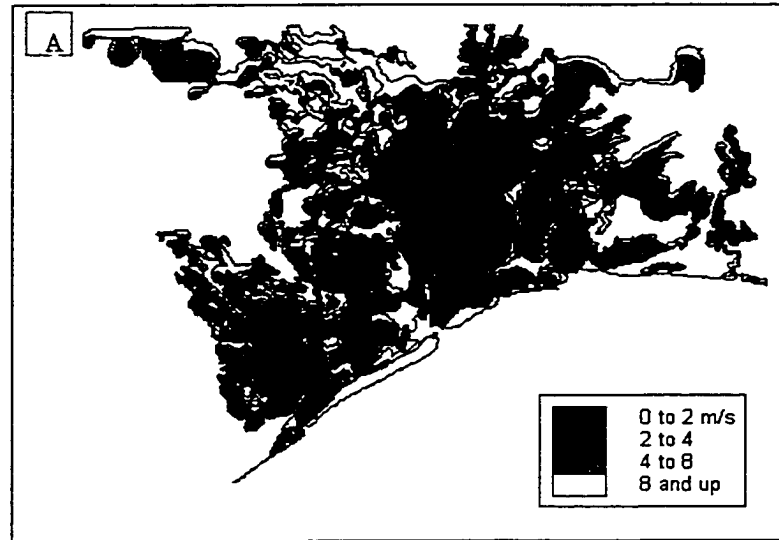


Figure 3. 9. Isopleths of U_c (m/s) in the lower Barataria Basin. Isolines represent the wind speed required to induce resuspension for a north wind (360°) (A) and a south wind (180°) (B). Each contour represents the region that would be subject to resuspension at the indicated wind speed.

wind speed and direction in Tables 3, 4 and 5 for the same water bodies. These estimates cannot be as easily verified in water bodies within the Barataria Basin because of mixing between water bodies.

Seasonal Resuspension Characteristics

From the characterization of winds during each period of this study and model estimates of U_c , we can begin to quantify the characteristics of resuspension (i.e. frequency, duration and areal extent) in the Barataria Basin. During the fall, winter and early spring (i.e. periods 1 – 4, 9 and 10) northerly component winds accounted for more than 65% of the wind energy during each period (Table 1). These periods also exhibited the highest mean daily wind speeds for this study (Figure 5). Areal resuspension estimates (Tables 3, 4 and 5) indicate that the windspeed necessary to affect 50% of bottom sediments in each water body, is 4 m/s. The region affected is much smaller for lower windspeeds. For northerly component winds of 4 m/s, more than 50% of bottom sediments in each water body were subject to resuspension, primarily on the southern side (Figs. 7, 8, and 9). During spring and summer (i.e. periods 5 – 8) southerly component winds accounted for more than 50 % of the wind energy during each period (Table 1). However, these periods exhibited the lowest mean daily wind speeds for this study (Figure 6). Areal resuspension estimates (Tables 3, 4 and 5) indicate that for southerly component winds of 4 m/s, over 45 % of bottom sediments in each water body were subject to resuspension, primarily on the northern side (Figs. 8, 9 and 10). During summer

Table 3.3. Cumulative bottom sediment resuspended (%) in Little Lake. The numbers under the wind direction headings represent the percent of bottom sediments (on an areal basis) that are resuspended at the wind speed in the left column. The percentages are cumulative as wind speed increases.

	Bottom Sediment Resuspension (%)							
U_c (m/s)	NW (315°)	N (360°)	NE (45°)	E (90°)	SE (135°)	S (180°)	SW (225°)	W (270°)
2	18.4	18.4	6.3	23.1	19.5	21.1	10.6	24.2
4	47.8	50.2	36.0	59.3	48.2	50.7	36.6	59.7
6	62.0	68.2	58.7	73.1	62.5	65.4	54.6	72.5
8	71.4	76.5	70.3	79.6	71.0	74.2	67.1	79.7
10	78.1	81.9	77.1	83.9	76.8	79.6	74.5	84.3

Table 3.4. Cumulative bottom sediment resuspended (%) in Lake Salvador. The numbers under the wind direction headings represent the percent of bottom sediments (on an areal basis) that are resuspended at the wind speed in the left column. The percentages are cumulative as wind speed increases.

	Bottom Sediment Resuspension (%)							
U _c (m/s)	NW (315°)	N (360°)	NE (45°)	E (90°)	SE (135°)	S (180°)	SW (225°)	W (270°)
2	0.0	2.6	1.9	2.9	0.9	4.8	6.9	2.9
4	32.0	53.0	60.6	58.6	30.3	55.2	56.5	61.6
6	53.7	72.3	74.8	74.2	54.3	71.7	72.0	77.2
8	68.6	80.8	81.5	82.4	68.6	79.8	79.8	83.7
10	76.9	85.2	85.6	86.5	76.1	84.2	84.3	87.4

Table 3.5. Cumulative bottom sediment resuspended (%) in the lower Barataria Basin. The numbers under the wind direction headings represent the percent of bottom sediments (on an areal basis) that are resuspended at the wind speed in the left column. The percentages are cumulative as wind speed increases.

	Bottom Sediment Resuspension (%)							
U_c (m/s)	NW (315°)	N (360°)	NE (45°)	E (90°)	SE (135°)	S (180°)	SW (225°)	W (270°)
2	16.6	28.4	18.3	29.3	20.3	32.4	23.2	28.9
4	47.5	62.6	50.6	57.1	48.4	59.4	48.7	57.2

months, (periods 7 and 8) west and east winds contributed significantly to the total wind energy; west winds accounted for approximately 20 % of wind energy during period 7, while east winds accounted for approximately 30 % of the wind energy during period 8 (Table 1). Again, areal bottom sediment resuspension estimates in Tables 3, 4 and 5 indicate that greater than 55 % of bottom sediments, in each water body, were subject to resuspension for easterly or westerly winds of 4 m/s. Winds of this magnitude (4 m/s) occurred during all periods of this study; and indicate that significant resuspension events should occur throughout the year as well. However, fall, winter and early spring appear to be the times when resuspension is most intensive (i.e. highest wind speeds) and frequent (i.e. wind speeds were greater than 4m/s approximately 80 % of the time) (Figure 10). In contrast, summer appears to be a time of lower resuspension intensity (i.e. lowest wind speeds) and lower frequency (i.e. wind speeds were greater than 4 m/s approximately 35 % of the time) (Figure 11). However, it should be noted that the frequency of thunderstorm occurrence is at a maximum during summer months (Hopkinson et. al., 1985), and because of their limited spatial influence most of these thunderstorms are not included in the wind data utilized for this study.

Seasonal Deposition

In conjunction with the water column resuspension work presented here, seasonal rates of deposition and erosion of particulate material to bottom sediments were investigated (Booth et al., 1999). By utilizing a naturally occurring radioisotope (i.e. ^7Be) as a tracer of particulate material, Booth et. al., 1999

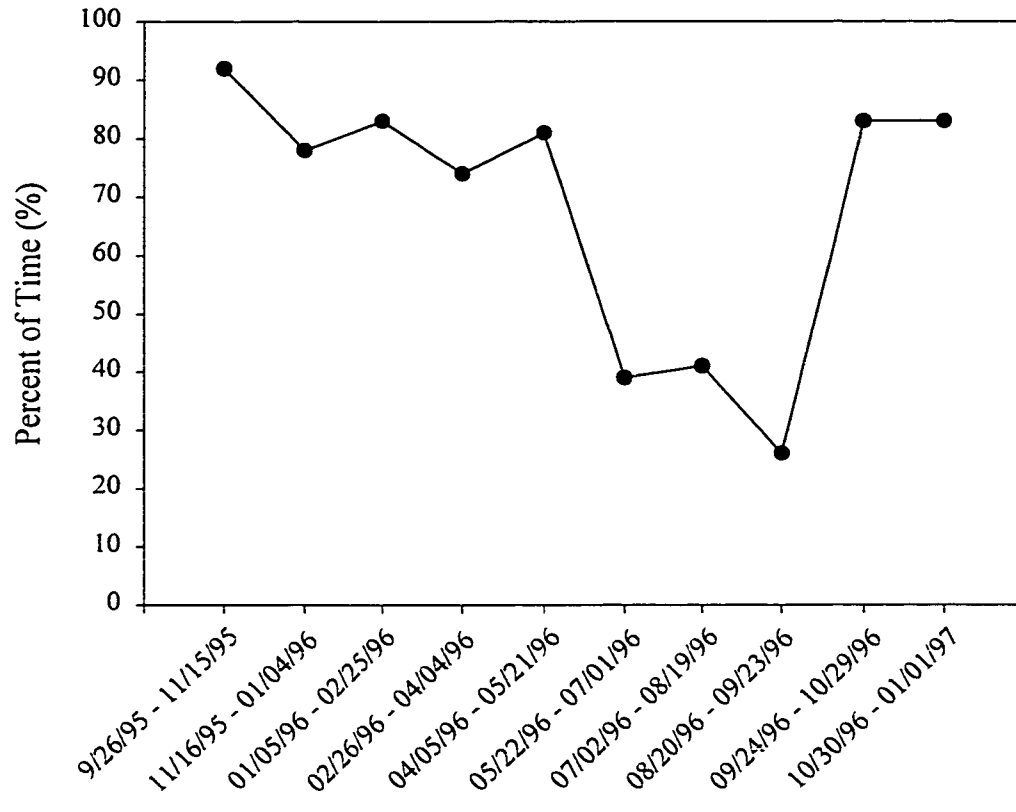


Figure 3.10. Percentage of time during each study period that the average daily wind speed was equal to or greater than 4 m/s.

quantified rates of net particle deposition and erosion at two contrasting sites, Little Lake (LLN) and Live Oak Bay (LOB), in the lower basin. The LLN station was located in a shallow (~ 1.5 m), large ($\sim 114 \text{ km}^2$) lake and was unprotected from wind exposure (i.e. large fetch). In contrast, the LOB station was located in a shallow (~ 1 m depth), small ($\sim 1 \text{ km}^2$) water body which was adjacent to the littoral edge of the surrounding wetlands, and more protected from wind exposure (i.e. small fetch). Sources of particulate material to the LLN station would include resuspended sediments from Little Lake as well as from water bodies north and south of the lake depending on the duration and strength of prevailing winds. Sediment sources to the LOB site include material from the surrounding marshes as well as resuspended sediments from water bodies south of the station (e.g. Hackberry Bay and Barataria Bay).

Particle deposition occurred throughout the study period (15 months) at each station (Figure 15). The annual deposition measured at the LLN site was primarily accounted for during two periods of contrasting winds, periods 5 and 9. In period 5 an abrupt shift from northerly to southerly dominant winds occurred (Table 1) resulting in the highest rate of sediment deposition measured at the LLN site (Figure 12). In contrast, during period 9 winds shifted from southerly to northerly dominant (Table 1) resulting in an intense erosional period (Figure 12). Spring and summer accounted for 75% of the net sediment deposition which occurred at the LLN site. The annual deposition measured at the LOB site was primarily accounted for during the fall, winter and early spring, periods 1 through 4. During these periods, greater

than 60% of the net sediment deposition for the 15 month study was accounted for (Figure 12), and winds were primarily from the north (Table 1).

The results derived from a combination of radioisotope, remote sensing and modeling techniques indicate that the annual transport of sediments (i.e. resuspension, redistribution and deposition) in the Barataria Basin varies seasonally. Down basin transport dominates during the cold front season (i.e. fall, winter and early spring) and up basin transport dominates during the late spring and summer. Further, sedimentation at any site will vary in relation to the orientation with the dominant winds and the size of the water body.

SUMMARY

Model predictions of sediment resuspension in Lake Pontchartrain (estimated from wind speed information and models of wind induced wave characteristics) show good agreement with surface water reflectance (i.e. turbidity) derived from satellite imagery. Based on this validation the seasonal characteristics of resuspension for the Barataria Basin were described.

Bottom sediment resuspension occurs throughout the year in the Barataria Basin. Annual characteristics for resuspension indicate that in fall, winter and early spring resuspension events are most frequent (mean wind speeds averaged ~ 5 m/s) and intensive (dominant wind speeds averaged ~ 6.5 m/s). Northerly component winds are dominant during these times and result in the down basin transfer of water and suspended materials. In contrast, late spring and summer exhibit less frequent (mean wind speeds averaged < 3 m/s) and less intensive (dominant wind speeds

averaged ~ 3 m/s) resuspension events. However, southerly component winds dominate during these time periods and result in an up basin transport of water and suspended materials. Thunderstorms occur with the highest frequency during the summer months and likely result in localized affects of resuspension and redistribution, as compared to the basin wide transport mentioned above.

Areal estimates of bottom sediment resuspension (based on contour plots of critical wind speed) indicate that northerly or southerly component winds of 4 m/s resuspend approximately 50 % of bottom sediments in Lake Salvador, Little Lake and the lower Barataria Basin. Winds of this magnitude occur most frequently during the fall and winter (i.e. > 80 % of the time), and least frequently during late summer ($< 30\%$ of the time). Areal resuspension estimates indicate that at winds of 10 m/s greater than 80 % of bottom sediments experience wave induced resuspension in the water bodies examined here.

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CONCLUSIONS

BULK MATERIAL TRANSPORT

Cumulative rates of short term (i.e. ~ monthly) sediment transport within the basin were variable, ranging from $-1.6\text{E}3$ to $1.42\text{E}4 \text{ g m}^{-2} \text{ yr}^{-1}$, and likely controlled by seasonal wind conditions and the orientation of the local environment to these winds. Locations most vulnerable to seasonal wind conditions are the central portions of bays and lakes. In contrast, locations proximal to the marsh interface exhibit short term rates of deposition several times higher than the long term burial rate. At these locations short-term sedimentation is enhanced by frontal passages occurring in the fall and winter.

Burial rates for subaqueous bottom sediments in the Barataria Basin ranged from 0.08 to 0.25 cm yr^{-1} . In general, cores collected from sites which were proximal to wetland vegetation and more sheltered had the highest sedimentation rates. The average burial rate for the more protected sites was 0.21 cm yr^{-1} , while the average burial rate for the less protected sites was 0.11 cm yr^{-1} . Burial rates appear to be controlled on a time scale that closely resembles the frequency of hurricanes impacting the basin.

PARTICULATE ORGANIC CARBON TRANSPORT

Data from this work indicate that POC is accumulating in bottom sediments at much higher rates in the short term (i.e. averaged over monthly time scales) ranging from 100 to $1000 \text{ g C m}^{-2} \text{ yr}^{-1}$ at two hydrologically contrasting stations, while POC burial rates (i.e. averaged over decadal time scales) from cores collected

throughout the basin, range from 8 to 37 g C m⁻² yr⁻¹. The difference between deposition and burial, 73 to 960 g C m⁻² yr⁻¹ represents the amount of organic carbon available for export to the Gulf of Mexico or accumulation in marsh sediments. Wind energy distribution information indicates that during the cold front season, strong northerly winds will tend to transfer material to the adjacent Gulf of Mexico (Booth et al., 1999). Additionally, the carbon that is transferred to the Gulf of Mexico may have marine carbon characteristics (i.e. low C/N values and $\delta^{13}\text{C}$ values of ~ 22 ‰) but actually be highly degraded terrestrial carbon (i.e. marsh detritus) from the deteriorating wetlands within the basin.

BOTTOM SEDIMENT RESUSPENSION CHARACTERISTICS

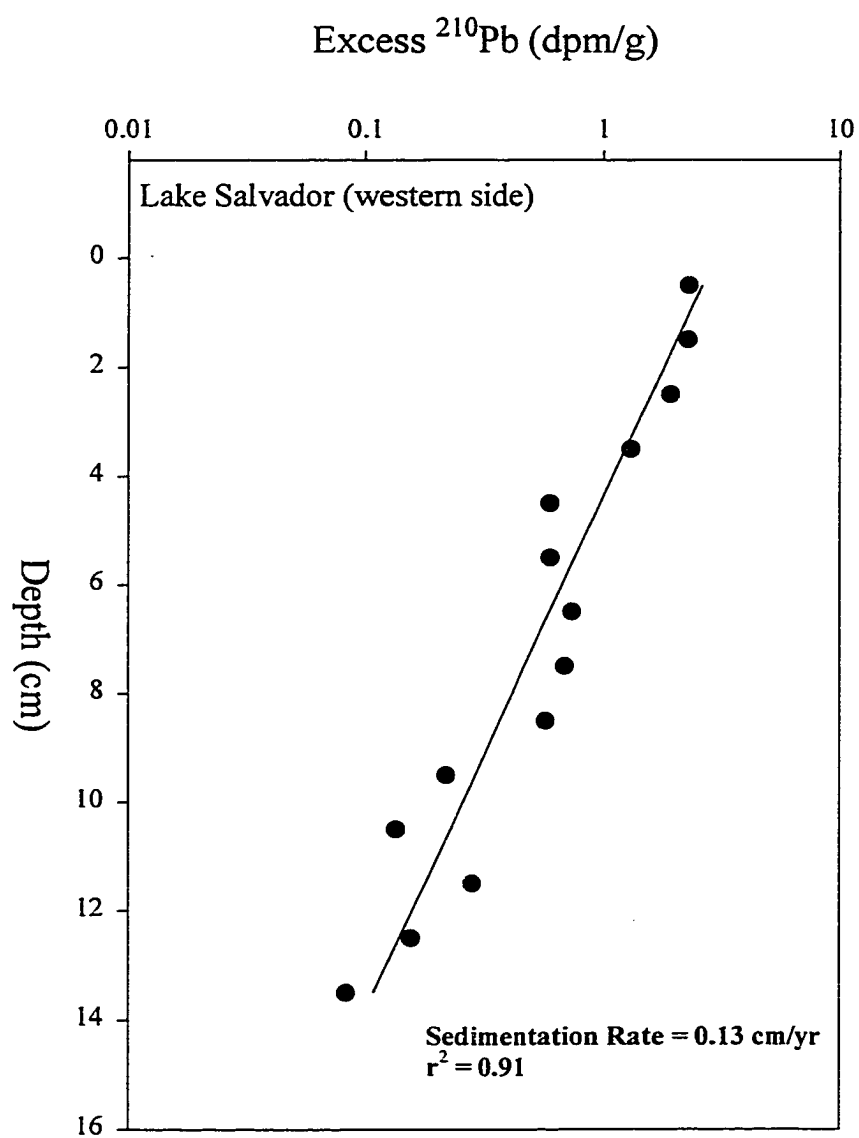
Model predictions of sediment resuspension in Lake Pontchartrain (estimated from wind speed information and models of wind induced wave characteristics) show good agreement with surface water reflectance (i.e. turbidity) derived from satellite imagery. Based on this validation the seasonal characteristics of resuspension for the Barataria Basin were described.

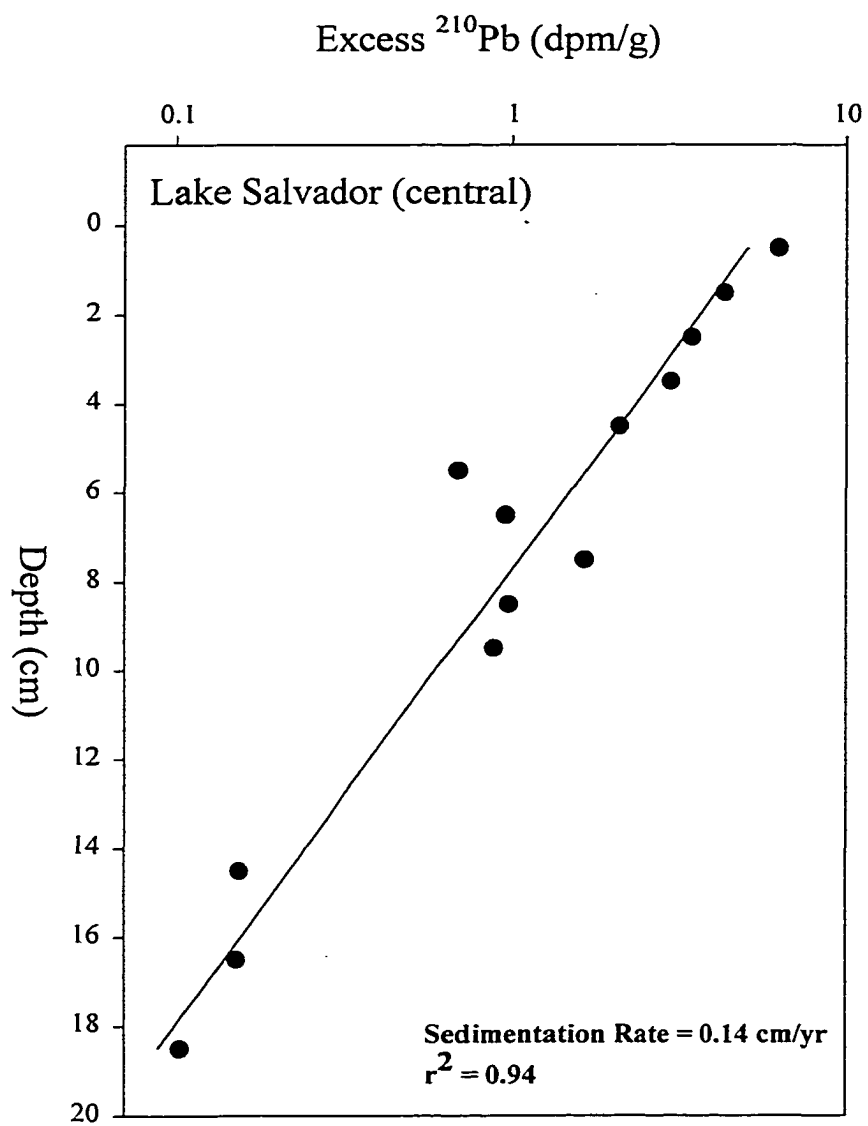
Bottom sediment resuspension occurs throughout the year in the Barataria Basin. Annual characteristics for resuspension indicate that in fall, winter and early spring resuspension events are most frequent (mean wind speeds averaged ~ 5 m/s) and intensive (dominant wind speeds averaged ~ 6.5 m/s). Northerly component winds are dominant during these times and result in the down basin transfer of water and suspended materials. In contrast, late spring and summer exhibit less frequent (mean wind speeds averaged < 3 m/s) and less intensive (dominant wind speeds

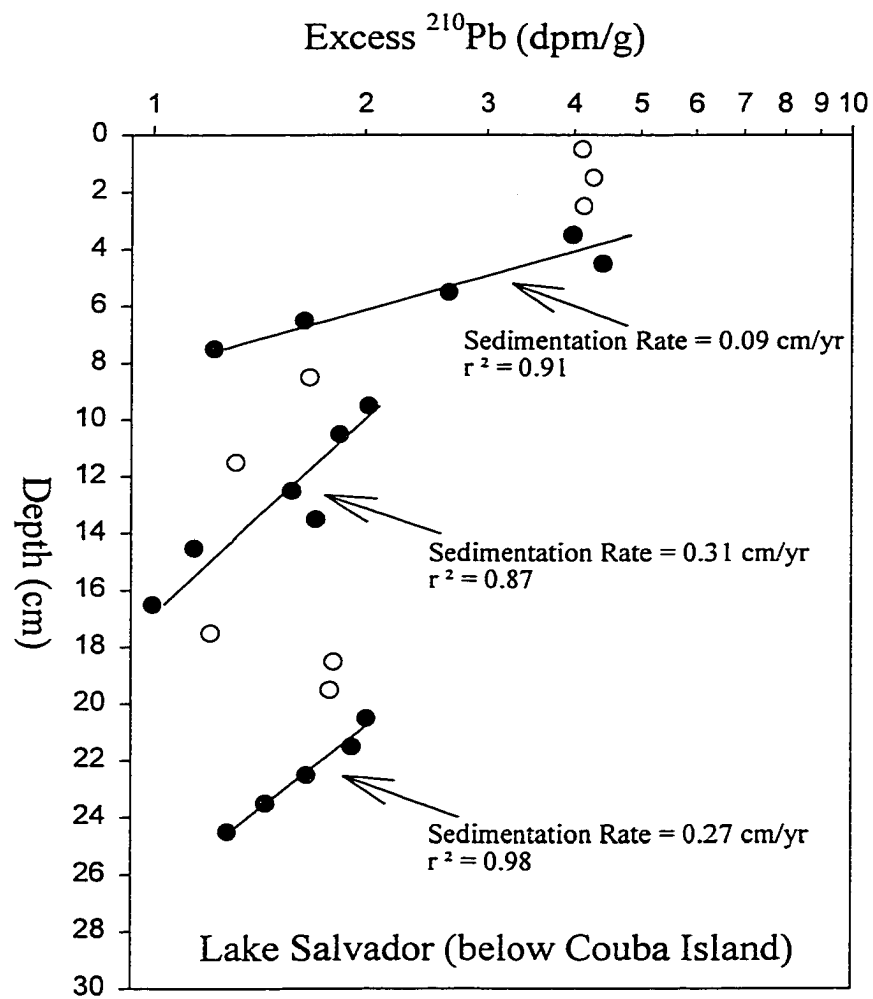
averaged ~ 3 m/s) resuspension events. However, southerly component winds dominate during these time periods and result in an up basin transport of water and suspended materials. Thunderstorms occur with the highest frequency during the summer months and likely result in localized affects of resuspension and redistribution, as compared to the basin wide transport that occurs in relation to seasonal prevailing winds.

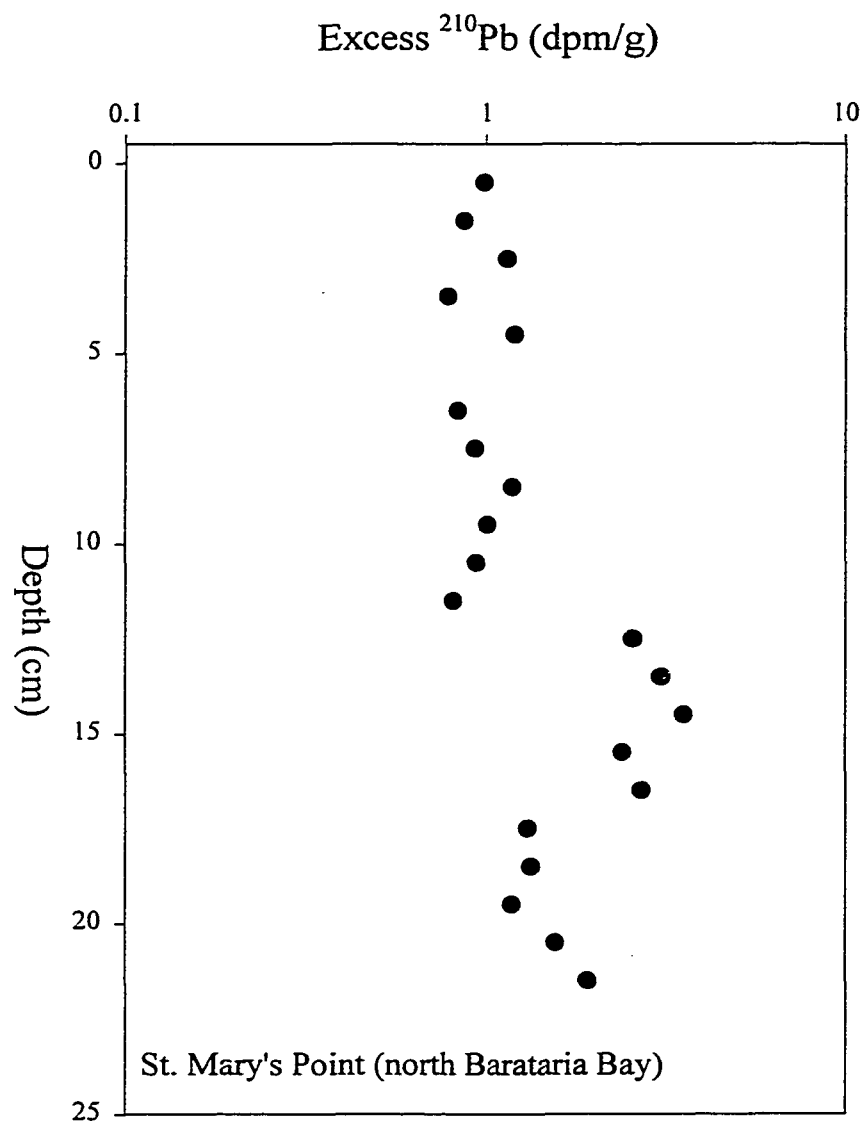
Areal estimates of bottom sediment resuspension (based on contour plots of critical wind speed) indicate that northerly or southerly component winds of 4 m/s resuspend approximately 50 % of bottom sediments (on an areal basis) in Lake Salvador, Little Lake and the lower Barataria Basin. Winds of this magnitude occur most frequently during the fall and winter (i.e. > 80 % of the time), and least frequently during late summer ($< 30\%$ of the time). Areal resuspension estimates indicate that at winds of 10 m/s greater than 80 % of bottom sediments experience wave induced resuspension in the water bodies examined here.

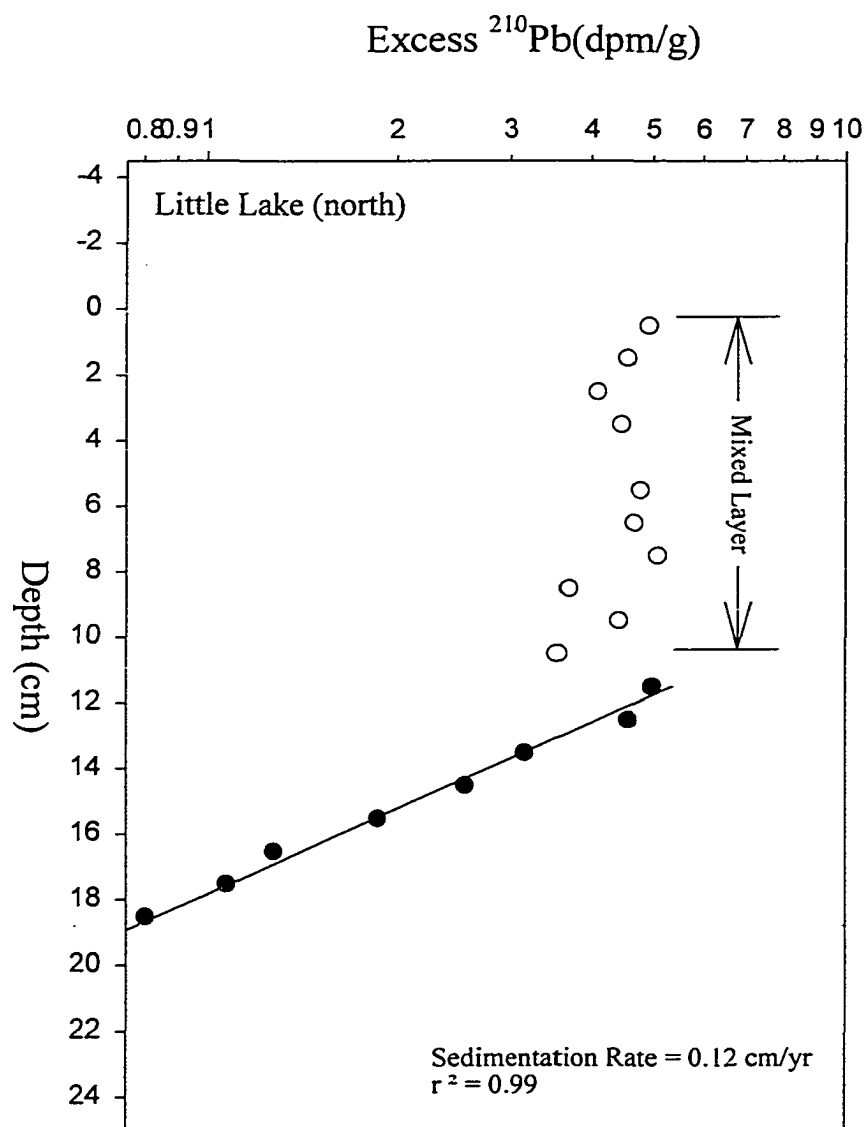
APPENDIX: EXCESS ^{210}Pb PROFILES FROM CHAPTER 1

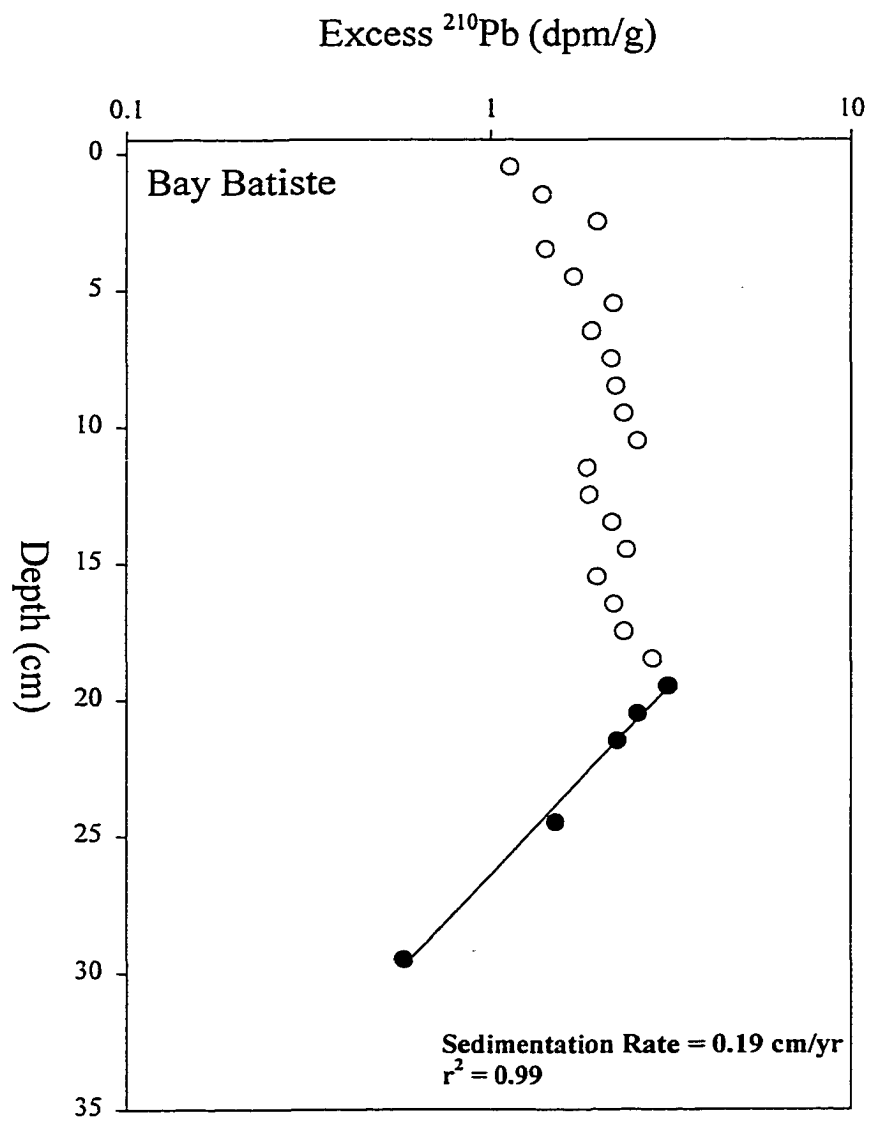


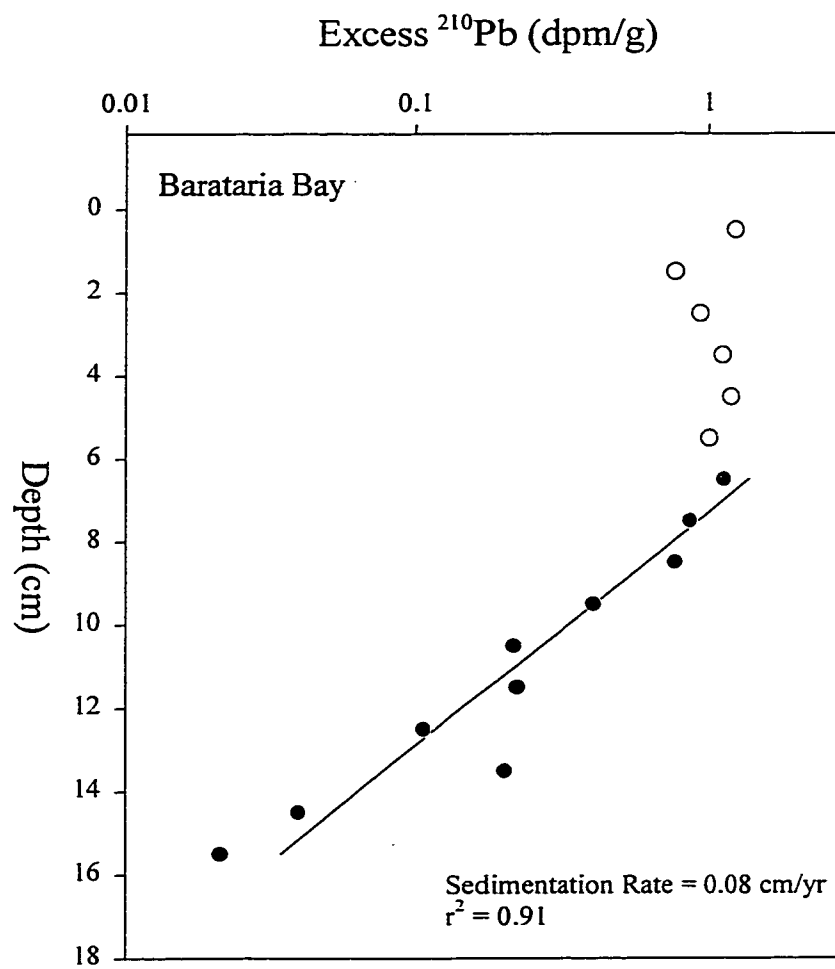


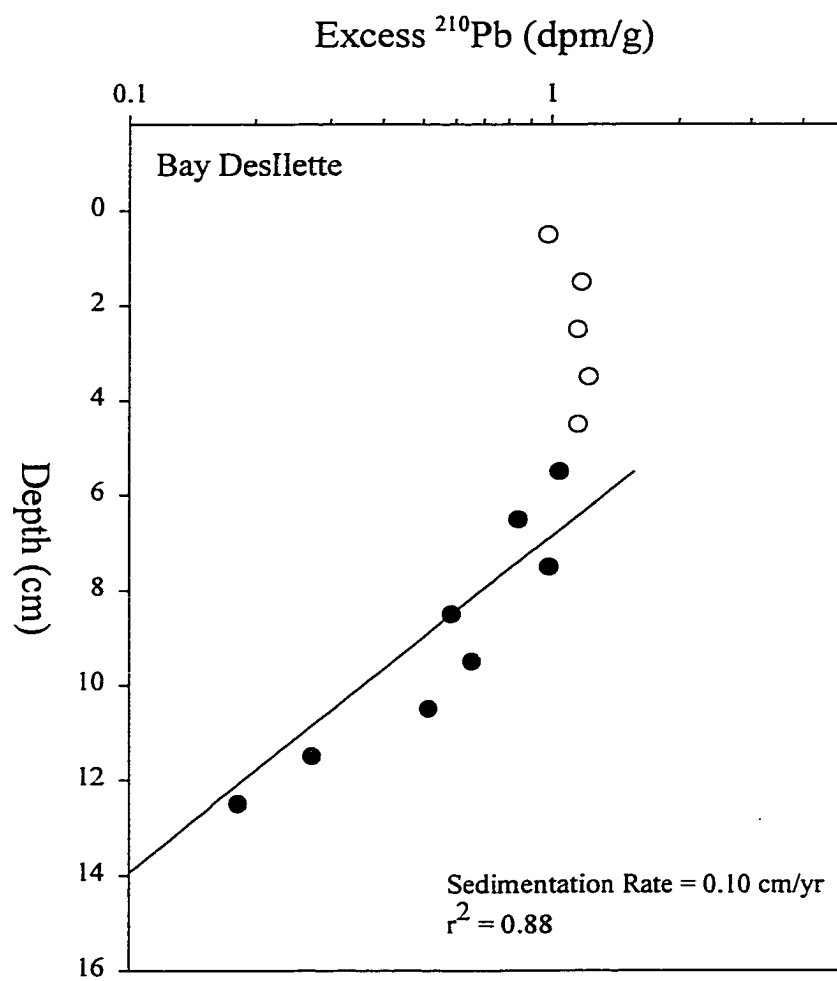


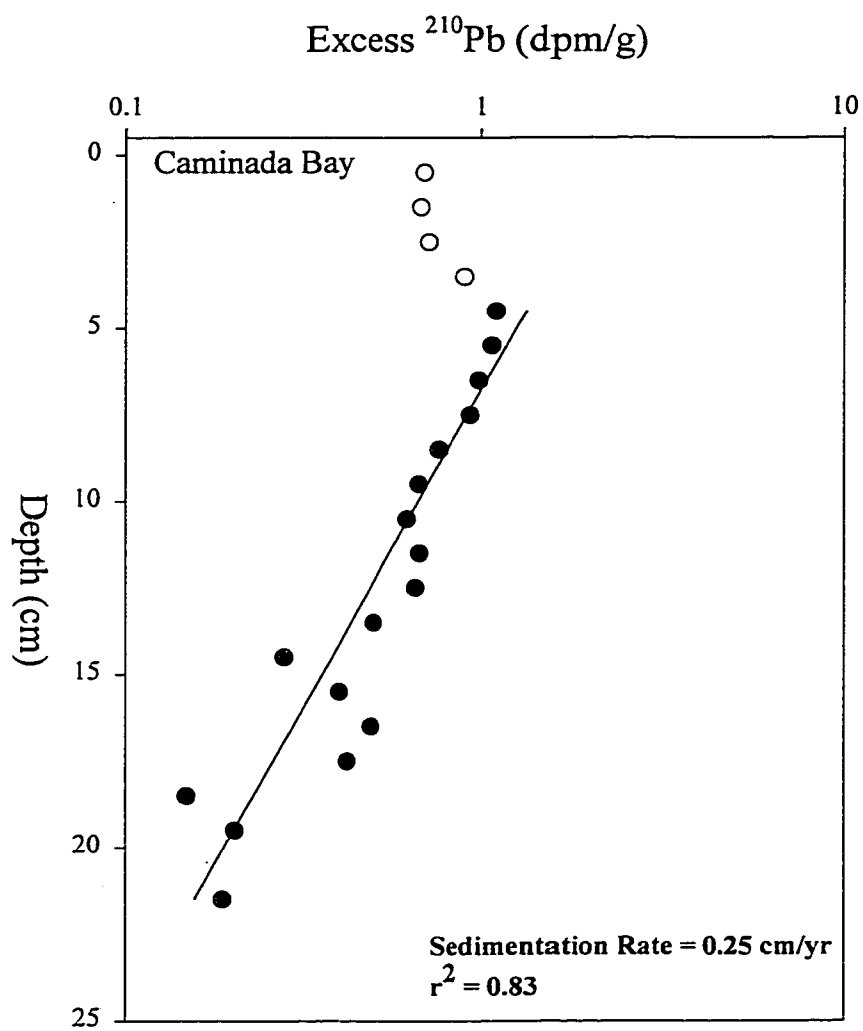












VITA

John Gregory Booth obtained a bachelor of science degree in 1988 from Southeast Missouri State University in Cape Girardeau. He then moved to southern Louisiana and was employed as a research technician in the geochemistry/radiochemistry laboratory of Dr. Brent A. McKee at the Louisiana Universities Marine Consortium (LUMCON) in Cocodrie. He married Lori A. Crump in 1990, and returned to college to pursue graduate studies at the Louisiana State University in Baton Rouge in 1991. In 1994, he obtained a master of science degree and his research focused on the transport of uranium isotopes in the Mississippi River. Their first child, John Garrett Booth, was born on June 10, 1996. In 1997, he accepted a research scientist position with NASA in the Earth System Science Office (ESSO) at the Stennis Space Center in Mississippi. Their second child, Jacob Scott Booth, was born on February 4, 1999. Also in 1999, Greg received the degree of Doctor of Philosophy. He continues to be employed with NASA and his research combines biogeochemical and remote sensing studies of the near-shore marine environment to better understand sediment transport and biogeochemical fluxes.

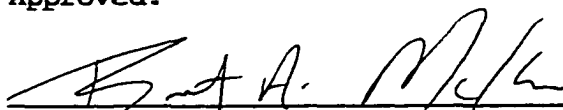
DOCTORAL EXAMINATION AND DISSERTATION REPORT

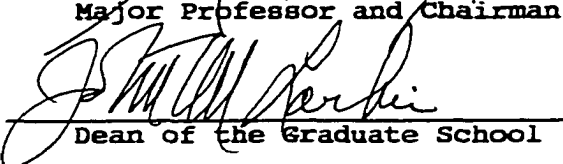
Candidate: John Gregory Booth

Major Field: Oceanography and Coastal Sciences



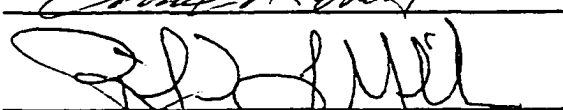

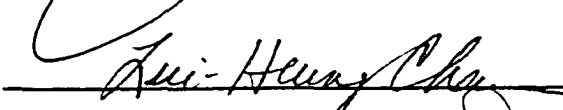
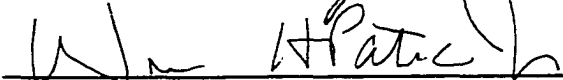
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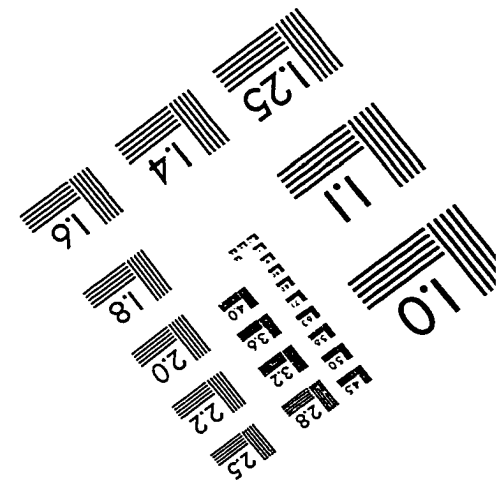
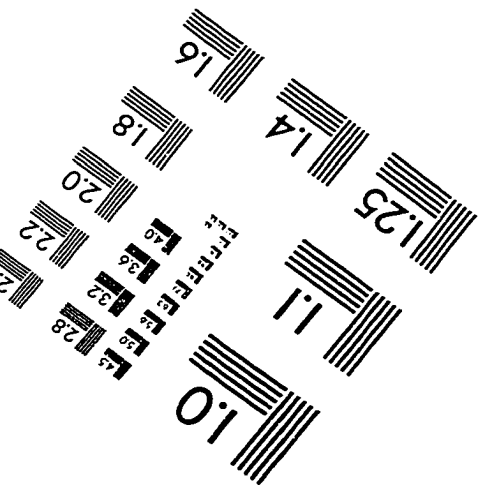
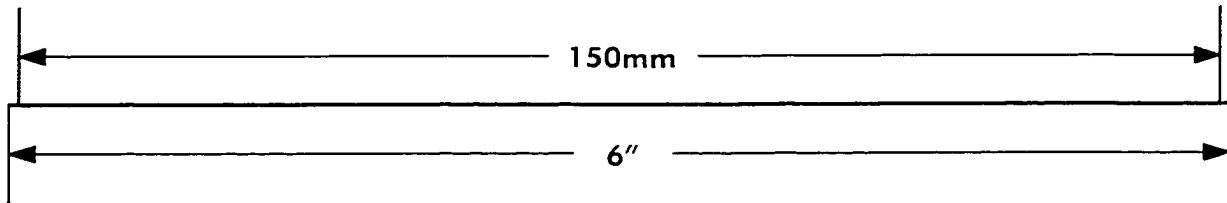
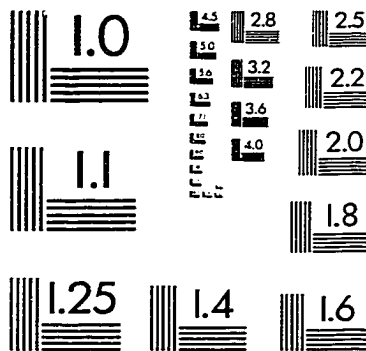
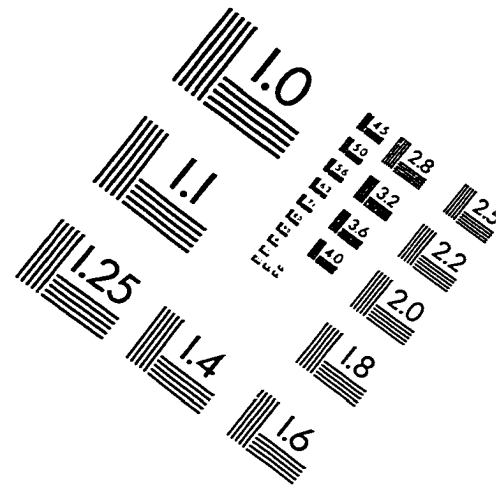
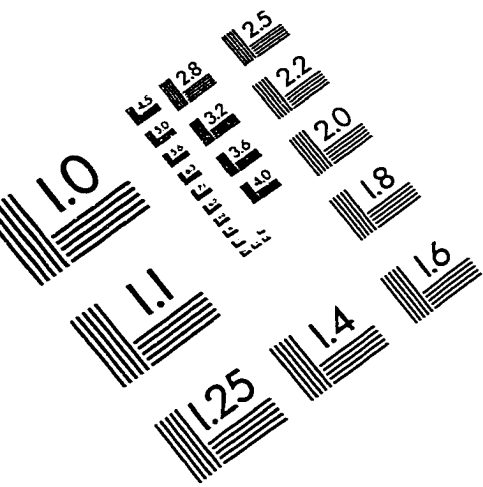
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